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PROCEEDINGS OF THE SOCIETY OF ARTS.

THIRTY-SEVENTH YEAR, 1898–99.

BOSTON, January 12, 1899.

THE 519th regular meeting of the SOCIETY OF ARTS was held at the Massachusetts Institute of Technology this day at 8 P.M., with Mr. George W. Blodgett in the chair. Twenty persons were present.

The report of the previous meeting was read and approved.

Mr. Walter Humphreys, of Boston, Class of '97, Massachusetts Institute of Technology, and Mr. Edward D. Mellen, of Cambridge, Class of '94, Massachusetts Institute of Technology, were elected Associate Members of the Society.

The Chairman then introduced Professor Jerome Sondericker, of the Massachusetts Institute of Technology, who read a paper on "Repeated Stresses."[1] Repeated stresses are of very common occurrence in engineering structures. The moving parts of machines are, as a rule, subjected to them. Connecting rods and parallel rods, pro-

[1] Published in full, *Technology Quarterly*, Vol. 12, No. 1, March, 1899.

pellers, shafts, car axles, ordinary wagon axles, etc., are all subjected to repeated stresses. Car rails and the parts of a bridge are also subjected to varying stresses as the loads pass on and off.

When wrought iron or structural steel is tested in an ordinary testing machine by pulling apart in tension, by bending, crushing, etc., the piece is broken by a load gradually applied once. The material, being ductile, is considerably distorted before fracture takes place, the circumstances leading to fracture being those which accompany the flow of a plastic mass. The circumstances accompanying fracture under repeated stresses are entirely different, so that the strength of a piece under such stresses cannot be learned from the results of an ordinary test.

The tests presented were made on rotating shafts, subjected to a transverse load, the stress, therefore, varied during each revolution between tension and compression of equal amounts. The specimens tested included wrought iron and structural steel, the steel varying in carbon from .08 per cent., or less, to .50 per cent., and in tensile strength from about 45,000 pounds to about 100,000 pounds per square inch. The speed of rotation varied from about 350 to 500 revolutions per minute. With the exception of a few cold-rolled pieces, the metal was tested in the condition in which it came from the mills. The investigations were conducted along two lines:

1. The determination of the elastic changes resulting from the repeated stresses, and the influence of such changes in causing fracture.

2. The influence of form, flaws, and local conditions generally in causing fracture. These were discussed in turn.

Tables were shown describing the results of repeated stresses on different specimens, and deductions from these presented in a very interesting way.

Mr. James E. Howard, of the Watertown Arsenal, took part in the discussion which followed, giving a statement of results obtained by him in a somewhat similar series of experiments.[1] His conclusions were generally to the same effect as those of Professor Sondericker. Several other gentlemen followed him, among them Professor Lanza, who spoke of the importance of these experiments as affecting the determination of a proper factor of safety.

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[1] Published in full, *Technology Quarterly*, Vol. 12, No. 1, March, 1899.

BOSTON, January 26, 1899.

The 520th regular meeting of the SOCIETY OF ARTS was held at the Massachusetts Institute of Technology this day at 8 P.M., with Mr. Desmond FitzGerald in the chair. One hundred and sixty persons were present.

The report of the previous meeting was read and approved.

Captain Alfred E. Hunt, of Pittsburg, Pennsylvania, Class of '76, Massachusetts Institute of Technology, Mr. James P. Clare, of Quincy, Massachusetts, Treasurer of the Hatch Storage Battery Company, and Mr. Horatio N. Parker, of Cambridge, Massachusetts, were elected Associate Members of the Society.

The Chairman then introduced Mr. George B. Francis, Resident Engineer of the Boston Terminal Company, who gave a "Description of the Construction and Other Features of the South Terminal Station."[1] Various statistics were given, showing the necessity of the station, and a statement made of the leading features of the problem, which involved a terminal station for one kind of business and a through station for another. The through station idea makes it possible to handle as many trains at the terminal as it is possible to run over a main line, and is realized by the use of loop tracks. Previous to any construction, a coffer-dam, to shut out the water, which at high tide would flood the level of the loop tracks, was necessary. This was entirely successful, and was supplemented by a waterproof coating of ten layers of tarred paper, swabbed together with hot coal-tar pitch. A continuous sheet amounting to 56,000 square yards was laid on a concrete base. On this the structure was built.

Mr. Henry J. Conant was then introduced, and presented a statement of the mechanical equipment of the station.[2] It comprises an extensive interlocking system for switching and signaling; a large power plant; elevators and lifts for carrying passengers and baggage; the warming, ventilation, and lighting of the various buildings; a plant for making ice for restaurants and for cars; for filtering and cooling drinking water; service for car heating, for charging air brakes prior to the departure of trains, etc.

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[1] Published in full, *Technology Quarterly*, Vol. 12, No. 1, March, 1899.

[2] Published in full, *Technology Quarterly*, Vol. 12, No. 1, March, 1899.

BOSTON, February 9, 1899.

The 521st regular meeting of the SOCIETY OF ARTS was held at the Massachusetts Institute of Technology, this day at 8 P.M., with Mr. George W. Blodgett in the chair. One hundred and twenty persons were present.

The report of the previous meeting was read and approved.

The Chairman then introduced Mr. H. F. J. Porter, of the Bethlehem Iron Company, who presented a paper on "Modern Methods of Steel Forging," with illustrations by the stereopticon. He spoke briefly of the methods used in historical times in the forging of swords, armor, and other more domestic implements; then of the rapid development brought about by improvements in the manufacture of steel; and finally of the equipment at Bethlehem for forging, particularly hollow and solid shafts, dynamo field rings, guns, armor plate, etc. Views were shown of the hollow shafts of the "Oregon" and of the "Brooklyn," forged at these works.

BOSTON, February 23, 1899.

The 522d regular meeting of the SOCIETY OF ARTS was held at the Massachusetts Institute of Technology this day at 8 P.M., with Mr. George W. Blodgett presiding. One hundred and ten persons were present.

The report of the previous meeting was read and approved.

Mr. Thomas P. Curtis was elected an Associate Member of the Society.

The Chairman then introduced Colonel E. D. Meier, Engineer-in-Chief of the Diesel Motor Company of America. Colonel Meier read a paper on "The Diesel Motor,"[1] illustrating his remarks with lantern views of the engine.

This new form of internal combustion engine was first described by Rudolf Diesel in 1893. It does away with many of the difficulties of the gas and oil engines, and at the same time gives a much higher efficiency. Its essential feature consists of the adiabatic compression of atmospheric air to a sufficient temperature to ignite the fuel (usually petroleum oil) which is injected at a determined rate during part

[1] Published in full in another column.

of the expansion, or working stroke. By this means perfect combustion is obtained. The first experimental engines were built at Augsburg in 1894 and 1896, one of 12 and another of 20 horse power. Two engines have been built in this country, and many others will be constructed during the summer.

BOSTON, March 9, 1899.

The 523d regular meeting of the SOCIETY OF ARTS was held at the Massachusetts Institute of Technology this day at 8 P.M., with Mr. George W. Blodgett in the chair. Fifty-five persons were present.

The report of the previous meeting was read and approved.

The Chairman introduced Mr. Theodore H. Skinner, Massachusetts Institute of Technology, '92, recently Superintendent of Construction at the University of Virginia, for McKim, Mead & White, who read an appreciative paper on "The Construction of the University of Virginia, Old and New."

A description was given of the construction of the early buildings, and photographs were shown of the original designs by Thomas Jefferson, and then of the buildings as actually developed in the process of construction. A high tribute was paid to the artistic genius of Thomas Jefferson. After the disastrous fire that destroyed the rotunda, a generous sum was subscribed by alumni and friends. With this the rotunda was rebuilt and made fireproof, and three large laboratories added. While the total sum subscribed was large, the amount available for each building was rather small, and the architects were forced to use a cement and brick construction which has proved peculiarly fitted to the exigencies of the case. Cement has been used wherever stone would ordinarily be employed; for pillars, caps and bases, cornices, walks, floors, etc. Interesting problems were encountered in the construction, particularly in that of the great amphitheater, the floor of which is supported by reversed catenary brick arches. The entire work was copiously illustrated by photographs thrown on the screen.

A. T. HOPKINS, *Secretary.*

GEOLOGY OF THE WACHUSETT DAM AND WACHUSETT AQUEDUCT TUNNEL OF THE METROPOLITAN WATER WORKS IN THE VICINITY OF CLINTON, MASS.

By W. O. CROSBY.

Read December 8, 1898.

Introduction.

In connection with the operations of the Metropolitan Water Board in the construction of the Wachusett Reservoir on the south branch of the Nashua River and the Wachusett Aqueduct Tunnel, two miles in length, which is to convey the water from the reservoir obliquely through the eastern wall or ridge of the Nashua Valley on its way to Boston and the Metropolitan District, I have enjoyed, during the past three and a half years, exceptionally favorable opportunities for becoming acquainted with the geological structure and history of this part of the Nashua Valley. The scope of my studies embraces, first, the hard rocks, and particularly the geological structure of the eastern ridge in the vicinity of Clinton, as developed by surface observations, and especially by the exploration of the site of the main dam (known officially as the Wachusett Dam) by borings and the excavation of the Wachusett Aqueduct Tunnel; and second, the drift deposits, or glacial geology, for which there can hardly be a finer field in New England, especially as revealed by the deforesting of the area of the Wachusett Reservoir and the numerous borings in the vicinity of the proposed auxiliary dams or dikes. These strongly contrasted glacial and preglacial phases of the geology suggest separate description; and it is proposed, therefore, to consider here only the hard rocks of the district, reserving the glacial geology of this part of the Nashua Valley for a subsequent paper.

I am indebted to the Metropolitan Water Board, and to Mr. F. P. Stearns, the Chief Engineer of the Board, for the most unrestricted and ample opportunity to make these studies, and for permission to publish the results of general scientific interest. My acknowledg-

ments are also due to Mr. T. F. Richardson and Mr. H. A. Miller, Department Engineers of the Board at Clinton, for many special facilities and courtesies.

Under the auspices of the United States Geological Survey, Professor B. K. Emerson is engaged upon a detailed and systematic study of the preglacial geology of the part of Massachusetts embracing the Nashua Valley; and it is gratifying to know that this important work is in such competent hands and well advanced toward publication. The main purpose of the present contribution, therefore, is simply to supplement Professor Emerson's work, for a very limited part of his field, by a somewhat detailed presentation of facts, chiefly structural rather than lithologic, which have been gradually, and often only temporarily, disclosed during the prosecution of the engineering works, and which are now in large part inaccessible, and the records of which are buried among official archives.

South of the Fitchburg Railroad the dominant and determining geological feature of the rather sharply accentuated eastern ridge of the Nashua Valley is a narrow band of plutonic rocks, which forms the axis of the ridge and at most points its crest, rising like a great longitudinal dike through an extensive series of argillaceous strata. Even in their more normal phases these sediments, which also include some quartzite and, in the town of Harvard, an interesting development of conglomerate, are more or less metamorphic — argillites and phyllites or sericite schist; while in close proximity to the plutonic masses they are commonly altered to typical and highly crystalline mica schists. The phyllites and schists are also commonly more or less carbonaceous, pyritiferous, or calcareous; and chiastolite is a not uncommon accessory, becoming in some parts of the district a striking and distinctive feature of the formation. The general line of strike is north-northeast, parallel with the axis of the valley, and a steep westerly dip prevails; while through the central part of the valley, especially, the argillites are, in general, highly contorted and wrinkled. A closed or isoclinal syncline, with its axial plane dipping to the west, is thus suggested; and this view of the structure of the valley, with slight modifications, has been generally accepted by geologists since the region was first studied by Hitchcock, sixty years ago.[1] It is not to its synclinal structure, however, but rather to the relatively rapid

[1] Occasional Papers, Boston Soc. Nat. Hist., 3, 154–161.

erosion of the least altered and softest part of the sedimentary series that the valley as a topographic feature is immediately due; and the highly unsymmetrical profile of the Nashua Valley as seen in the unequal heights of its eastern and western rims, and the fact that

FIG. 1.

the Nashua River closely follows the base of the lower eastern ridge, is best explained by its longitudinal relation to the eastern or seaward slope of the Wachusett-Watatic mountain range or height of land.

The plutonic rocks of the eastern ridge include both basic and acidic types, the latter largely predominating. The basic rocks are

various phases (mostly secondary) of what might originally, perhaps, have been called diorite, and it is still convenient to use that designation, although through the combined influence of dynamical and chemical processes, chiefly shearing and chloritization, the rock has been largely metamorphosed to more or less typical chlorite and biotite schists. The acidic rocks are different types of granite — chiefly a very coarsely porphyritic biotite granite and an unusually well characterized muscovite granite; and the latter often assumes, where penetrating the schist, a distinct pegmatitic phase.

Although my study of the hard rocks covers, in a general way, the entire valley, close and detailed observations have been confined to the vicinity of the main dam and the tunnel, or the area represented by the accompanying map (Figure 1). But even in this limited tract most of the rock types indicated above — both sedimentary and plutonic — are well developed; and the main purpose of this paper, as already indicated, is to place on record the facts brought to light, often only temporarily, by the engineering operations.

My studies have not led to any definite conclusion concerning the geological age of these rocks. Both the sedimentary and plutonic types bear the characters of a high antiquity; and a comparison with the formations of the Boston, Norfolk, and Narragansett Basins makes me reluctant to accept the suggestion of the highly carbonaceous and even coaly or graphitic character of a small part of the sediments that they are Carboniferous. The sedimentary rocks are undoubtedly older than the plutonics, by which they are freely intersected; and the coarsely porphyritic structure of one granite and the muscovitic character of the other plainly suggest their formation at a great depth, in a truly abyssal zone. Except that they exhibit a more pronounced regional or general metamorphism, the sediments are not unlike the Cambrian strata of the Boston Basin; and that we have here an originally deeper portion of the Cambrian complex of Eastern Massachusetts appears, on the whole, the best provisional correlation.

Distribution, Characters, and General Relations of the Rocks.

In the vicinity of Clinton, and especially on the line of the tunnel, the geological structure of the eastern ridge of the Nashua Valley is rather more complex and interesting than at almost any other point;

and, regarded simply from the point of view of the light which their construction might throw upon the geology of the region, the dam and tunnel (and the same is true of the dikes) could hardly have been more advantageously located. Even the fact that the tunnel, in its southeasterly course, gives an oblique section of the ridge, causes it to pierce a greater variety of rocks and contribute more to the elucidation of the geological structure than would otherwise be the case.

The map is a graphic summary of the main facts. It shows (1) that the great series of argillaceous and siliceous sediments — argillites. phyllites, schists, and quartzite — is divided, approximately parallel with the strike, by two dike-like bands of porphyritic granite, one on either side of the river, the erosion of the intervening narrow band of relatively soft and yielding sediments having determined the gorge-like character of the valley of the modern Nashua in the vicinity of Clinton; (2) that the more eastern band of porphyritic granite is bordered on the east by a large compact body of the dioritic rock; and (3) that both the porphyritic granite and the diorite appear to end southward against a great boss of the muscovite granite.

Sedimentary Rocks. — From west to east — from the vicinity of the North Dike to West Berlin — the sediments present the following diversified section, the differences being partly original and partly secondary, the results of unequal metamorphism. West of Burdette Hill, on which the Clinton reservoir stands, in the North Dike area, the prevailing rock, as indicated by the natural ledges, and more especially by the numerous borings, is a soft and fissile light gray to dark gray, and even black argillite or phyllite. The variation in color is undoubtedly due in part to unequal surface oxidation, but in part, also, to original differences in the proportions of carbonaceous matter. The black layers, especially, are commonly more or less pyritiferous; and the rock is in general highly contorted and wrinkled, as may be well seen in the ledges west of the Catholic Cemetery. On the summits of Burdette Hill and Cedar Hill, on which the main part of Clinton is built, near the western band of porphyritic granite, the phyllite is in part more siliceous, and grades into true quartzite, of which there are some heavy intercalated beds.

The narrow band of sedimentary rocks separating the two bands of porphyritic granite is in part true mica schist along its eastern border, and embraces some typical quartzite, as may be well seen in the ledges near the bend of the river, half a mile south of the main dam. It is

for the most part, however, especially as revealed by the tunnel and the cores of the diamond drill borings, either gray, distinctly argillaceous, and rather firm and massive (a true phyllite), or black, highly carbonaceous (coaly and graphitic), semi-crushed, crumbling, and fissile. The total breadth of this belt in the vicinity of the tunnel and dam is nearly 900 feet, and the best general view appears to be that the crumpled carbonaceous beds mark the axis of an unsymmetrical syncline, the limbs of which have been largely cut away by the great dikes of granite. The only natural exposures of the highly carbonaceous beds are in the east bank of the river, opposite the Lancaster Mills.

The diorite area is bordered on the east by a rather coarse and gritty, hard and massive schist. The characters of this rock mark it very plainly as a metamorphic sandstone, and at some points it is now more properly a micaceous quartzite than a true schist. In structure it is almost as massive as the diorite; but it lacks the prevailing green (chloritic) color of the latter rock, and the two rocks are in general readily distinguished. In the vicinity of the tunnel the gritty schist has a general strike south, 45° to 60° east, or nearly parallel with the tunnel; while the dip is throughout high to the northeast. Hence, although the tunnel runs for almost exactly a thousand feet in this rock, no great thickness is indicated.

Immediately southeast of shaft No. 3 of the tunnel, the gritty schist changes rapidly, but not abruptly, to a much finer grained, softer, and more distinctly bedded rock, having the same strike and dip, and varying in character between an argillaceous or slaty mica schist and a micaceous slate. It is often thin bedded or shaly, but remarkably free from contortions or wrinkles, and rarely pyritiferous or carbonaceous. With the exception of about 200 feet of muscovite granite, the tunnel is in this slaty schist practically all the way from shaft 3 to shaft 4, or fully 2,100 feet; but most of the way the tunnel is approximately parallel with the strike, and, as before, only a moderate thickness is indicated. Near shaft 4 the schist resumes its normal north-northeast strike, with a westerly dip of 80°–90°, mostly about 85°, and holds this attitude to the eastern end of the tunnel. Throughout this distance of about 2,200 feet it is highly metamorphic —a true schist; and yet, as the cut on the Central Massachusetts Railroad clearly shows, it is in part of a highly graphitic and pyritiferous character.

The abnormal strike of the schists on the line of the tunnel between the diorite and shaft 4, or in the angle between the diorite on the north and the muscovite granite on the south, will be more fully considered in a later section. Farther north, on the direct road from Clinton to West Berlin, the strike is normal across the entire section east of the diorite.

Porphyritic Granite. — The western band of porphyritic granite first appears on the north in the ledges on the railroad north of the river and northeast of Clinton. It forms the abrupt eastern slope of Cedar Hill, on which Clinton stands, and of the col, or ridge, connecting this hill with Burdette Hill, on which the Clinton reservoir is situated. On the line of Chestnut Street the granite appears to expand abruptly, crossing the river, and having thus afforded a foundation for the dam of the Lancaster Mills. In Burdette Hill the granite widens rapidly, cutting obliquely across the phyllites and quartzites on the west, and attaining a breadth on the line of the main dam of about 2,000 feet. South of this hill the granite sinks beneath a broken plain of modified drift. But the North Dike borings prove that it is not interrupted. It appears in conspicuous ledges along the southern base of the plain, and again rather obscurely on Cunningham Brook, west of the old brick yard.

The granite of this belt is normally very coarsely and profusely porphyritic, being in large part crowded with feldspar phenocrysts from 1 to 3 inches long; but toward the margins of the belt the phenocrysts become elongated, broken, and indistinct, and the porphyritic structure gradually fades out with or without the development of a more or less pronounced laminated or gneissic structure. The gneissoid character is, perhaps, most clearly shown in the ledges along the west bank of the river in the vicinity of the main dam.

The relations of this belt of granite to the inclosing sedimentary rocks are most satisfactorily exhibited on the ridge between Cedar and Burdette Hills, in the ledges between Chestnut and Grove Streets. The granite, which is here devoid of gneissic structure, and rather fine grained, cuts the metamorphic slate and quartzite in every direction; and for a breadth of 50 feet or so the granite is, at some points, crowded with large and small angular fragments of the hard and massive sediments. The eastern contact, as disclosed by the borings on the site of the main dam, will be described in a later section.

The eastern band of porphyritic granite begins on the southwest,

near the Central Massachusetts Railroad, and forms the crest of the main ridge northward far beyond the limits of the map. Carvill Hill, immediately south of the line of the tunnel, affords a good surface section of this belt, its width here being about 2,000 feet. Between the tunnel and the Acre (an eastern suburb of Clinton) the western border of the granite is quite plainly broken, as if by a fault, which might be regarded as accounting also for the corresponding break noted in the western belt on the line of Chestnut Street (see map). Midway between the Acre and Bolton Station, and immediately north of the station, small quarries have been opened in the granite, displaying to good advantage its massive structure and its coarsely porphyritic texture, which is even more pronounced than in the western belt. At the Acre, on the northwest side of the road to Bolton Station, the contact of the granite and schist is exposed, and a little farther northeast on the other side of the road is an outcrop of massive gray slate, which is probably an inclusion in the granite. The contact is also nearly but not quite exposed on the east side of Boylston Street about a quarter of a mile south of the tunnel. On the southeast side of Carvill Hill the granite and diorite are seen near each other, but not in contact.

Everywhere near its contact, alike with the schist on the west and the diorite on the east, the granite of this belt is non-porphyritic and distinctly gneissoid. The lamination, which is invariably parallel with the contact, is, near the contact, often extremely fine and perfect. But within a few yards from the contact, as a rule, we pass gradually to the normal coarsely porphyritic granite. The most complete and satisfactory surface section of this great dike, as previously noted, is afforded by Carvill Hill, and especially by its abrupt southwestern slope. The gneissic structure is plainly marked throughout the entire breadth of the granite, especially by the lenticular forms of the quartz, and the usually parallel or approximately parallel orientation of the great feldspar phenocrysts. Through the western middle portion of the belt the normal granitic structure is best preserved; but advancing toward the schist, and more especially toward the diorite, the feldspars show distortion by stretching and cracking, which increases slowly at first, and then more rapidly until they finally become. like the quartz, mere strings. The origin or genetic significance of this interesting structure will be considered in a later section.

Diorite. — Although the distribution of the outcrops of this rock

is favorable to its occurrence in one large compact area, the facts are, perhaps, sufficiently meager to permit other interpretations. On the line of the tunnel, however, the diorite is unquestionably continuous for a breadth of 2,200 feet from the porphyritic granite on the northwest to the gritty schist on the southeast. The diversified aspects of this rock resulting from a varying combination of metamorphic influences have been noted. At some points it appears to be still a fairly normal diorite, composed of plagioclase and hornblende; and exhibiting at times an original flow structure. But in the main the original constituents, and especially the hornblende, have given way to secondary species, among which chlorite and biotite are most conspicuous. The diorite is also, even in its most altered forms, commonly and sometimes highly pyritiferous; and the secondary character of the pyrite is plainly indicated by the fact that its bright unaltered crystals appear to be especially characteristic of the most altered or more thoroughly chloritized portions of the diorite.

The diorite is, throughout, more or less distinctly foliated or schistose in structure, and in fairly definite directions conforming with the bordering granite and schist. Unlike the granite, the foliation is not confined to nor specially more marked in the marginal portions of the formation; and there seems to be no reason to doubt that it is a secondary feature of the diorite, and the product of dynamic metamorphism; although the question might be raised as to whether the pressure, in its turn, may not in part, at least, have originated in the chloritization and general hydration of the rock.

Concerning the relations of the diorite to the sedimentary rocks, the evidence is very scanty. In fact, I have observed no facts bearing directly upon this problem except such as were disclosed by the tunnel, and to be noted later; but these it may be stated have appeared to be sufficient to show that the diorite is younger at least than the gritty schist. The relations of the diorite to the porphyritic granite are less obscure. At the northern end of the belt, north of the direct road from Clinton to West Berlin, the granite clearly cuts the diorite in many irregular and branching dikelets, and incloses angular fragments of the diorite of all sizes up to 50 feet or more in diameter; and similar facts were brought to light by the tunnel. In several of the ledges to be crossed and covered by the south dike the diorite is intersected by dikelets of granite. The large ledge or group of ledges east of the dike between the highway and the Central Massachusetts

Railroad is of particular interest in this connection. The rock is chiefly fine gneissoid granite, but along the north side especially there is considerable dark hornblendic and distinctly laminated diorite. The relations of the two rocks are very clear. The granite dikelets cut the diorite parallel to the lamination, and elongated pieces and slabs of the diorite are inclosed in the granite parallel to the gneissic structure of the latter rock. The lamination of the two rocks is thus substantially conformable, being approximately vertical, with east-west trend. Where most closely involved with the diorite, the porphyritic structure of the granite is commonly wanting; and the natural ledges, especially north of Berlin Street, afford strong indications of a blending of the granite and diorite. There seems, in fact, to be little reason to doubt that these two rocks are successive products of one and the same original magma, formed as usual in the order of decreasing basicity; and the diorite masses, it is probable, are, to some extent, original segregations from the granite magma.

Muscovite Granite. — Southward, as the map shows, this type appears to take the place of both the porphyritic granite and the diorite; and within the limits of the map it forms two prominent hills — Snake Hill and Mile Hill. The outlines of this area are at no point sharply defined in surface exposures; but that its northern border follows closely the contours of the hills is reasonably certain, and definitely proved for the northeast side of Snake Hill by the tunnel.

In lithological character this is the most uniform rock of the entire district — a rather coarsely crystalline one-mica granite, and that mica a silvery muscovite. The gneissoid structure so characteristic of the marginal portions of the porphyritic granite has been observed only on the eastern border of the muscovite granite; but it is here remarkably perfect. On the Central Massachusetts Railroad, immediately east of the brook which winds around Snake Hill, is a rock cutting over 600 feet long in a beautifully gneissoid phase of the muscovite granite. The lamination crosses the railroad very obliquely, striking northeast-southwest, and dipping northwest 45° to 80°, but mainly 45° to 60°. The gneissoid structure, which is in the main very fine and regular, is not due to any appreciable degree to the parallel orientation of the muscovite; but chiefly, as in the porphyritic granite, to the drawing out of the quartz and feldspar. Quite marked slickenside surfaces coincide with the foliation. The foliation

becomes less distinct westward, and west of the brook is another cut between 100 and 200 feet long in which the structure gradually dies out, the gneiss fading into the normal muscovite granite. The tunnel supplements this exceptionally good surface exposure by showing that this highly foliated granite is closely and conformably bordered on the east by the schist; and that the structural relations are the same, therefore, as with the gneissoid phase of the porphyritic granite.

That the muscovite granite is eruptive through the schist is still more conclusively shown by the irregular, isolated masses of schist inclosed in the granite over the summit of Mile Hill. These are to be regarded as mere remnants of a once continuous covering of schist over the batholite; and the fact that they retain the normal dip and strike, with the bedding of the schist abutting squarely downward against the granite, is a plain indication that this great body of granite, like a true batholite, has made room for itself, and hence must in part, at least, have been formed, by melting and absorbing large volumes of the schist.

Concerning the relations of the muscovite granite to the porphyritic granite the evidence is not so clear. Following the analogy of the essentially similar rocks of New Hampshire, the muscovite granite is probably the general equivalent of the Concord granite and younger than the porphyritic granite, in which case it must also be younger than the diorite. In this connection it may be noted that in the porphyritic granite are occasional dikes up to 10 feet or more in width, of a fine and even-grained granite which might, perhaps, be correlated with the muscovite granite, but the micaceous element has not a distinct macroscopic development, and it appears best on the whole to regard it as a later non-micaceous, as well as a non-porphyritic phase of the same magma as the porphyritic granite.

Structural Details of the Site of the Wachusett Dam.

The general topography of the dam site can be gathered from the accompanying photographic illustrations. Figure 2 shows the river as it appeared in 1895, before the deforesting of its banks, with the drilling apparatus at work upon rafts, and the till-clad eastern slope of carbonaceous phyllite. Figure 3 is a view directly across the river from a point well up on the eastern slope, from which the surface soil has been removed, and showing the coffer-dam which now turns the

FIG. 2. — SITE OF THE WACHUSETT DAM, LOOKING SOUTHWEST (1895).

FIG. 3. — SITE OF THE WACHUSETT DAM, LOOKING WEST (1898).

FIG. 4. — NASHUA RIVER, LOOKING SOUTH TOWARD THE SITE OF THE WACHUSETT DAM.

water of the river into the tunnel, and the abrupt western granite slope, made still more abrupt by a heavy bench of modified drift, and surmounted by the bold ledges of coarsely porphyritic granite forming the southern brow of Burdette Hill. Figure 4 is a view looking south or up stream toward the site of the dam in the distance, giving a general profile of the valley at that point, and showing the normal flood-plain of the river as laid bare by drawing off the water of the Lancaster Mill pond. The normal elevation of the surface of the river, as shown in Figure 2 and in the following sections, is 288.6 feet above low tide. The height of the bench or terrace of modified drift shown in Figure 3, and less distinctly on the right side of Figure 4, is about 390 feet above the same datum. This plain marks the principal level of the glacial lake of the Nashua Valley. Extending southward from it, and forming the west bank of the river above the coffer-dam, is a beautiful esker, which is shown in several of the sections, one of the diamond drill borings having been located on its crest. The elevation of the summit of Burdette Hill is about 530 feet, and of the crest of the eastern ridge above Boylston Street, 480 feet.

The borings, some 500 in number, made partly with the diamond drill but chiefly with the wash drill, on the site of the Wachusett Dam, and covering the entire breadth of the river and its immediately inclosing slopes for a distance up and down stream of nearly 300 feet, have disclosed in detail and with a high degree of accuracy the character and structure of the bed-rocks, the form of the bed-rock surface, and the depth and character of the superficial deposits or drift. I have made a careful study of the thousands of samples from the borings and of the accompanying notes, and have endeavored to correlate and interpret the borings geologically. The chief results of this study are given in the following sections, selected from a more complete series, all of which were drawn before the draining of the Lancaster Mill pond and the building of the coffer-dam.

The channel, or original bed of the river before the construction of the dam at the Lancaster Mills, lies under the west side of the river, the mean depth of water here being about 20 feet. To the east of this lies what was formerly the flood-plain of the river under 10 to 12 feet of water. Except at a few points on the slope above the west side of the river, the bed-rock is nowhere exposed, but is buried under a varying depth of drift — till on the eastern slope, and modified drift (sand and gravel) under the river and on the western slope. The

depth of drift under the river is considerable — 20 to 60 feet — and clearly fills a well-defined gorge between a sloping wall of metamorphic slate or phyllite on the east, and an abrupt wall of granite on the west; and the channel of the modern river is shown by the profiles to be directly over this granite escarpment, which varies in height from 20 to nearly 50 feet. The deepest part of the gorge is at the foot of this escarpment and on the contact between the granite and slate.

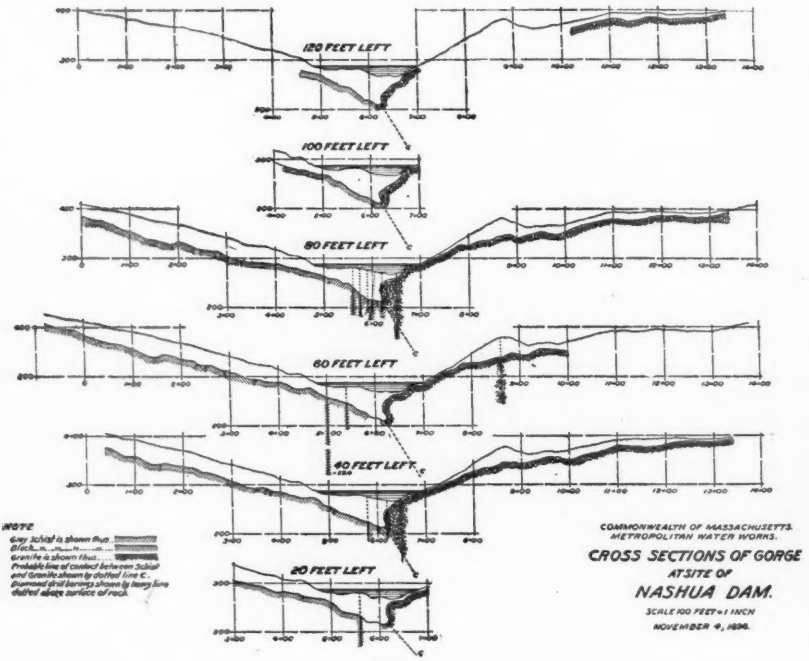


FIG. 5.

The slate or phyllite is chiefly the gray variety — a distinctly argillaceous, firm and massive rock. The diamond drill cores show that the stratification is obscure, being marked chiefly by occasional slickenside or shear planes, and the rock is rarely distinctly fissile or schistose except for a slight depth below the weathered surface. It is normally slightly pyritiferous and calcareous, and minute veinlets of quartz and calcite often form a complete network in the rock, increasing its massive character. The solid and massive structure of this normal slate is seen in the fact that in the diamond drill borings it cores nearly as well as the granite. Two principal variations from this type have been

noted. First, it becomes to a limited extent more siliceous, and passes into a slaty quartzite of flinty hardness. Second, it becomes distinctly and even highly carbonaceous, the carbon assuming, as previously noted, both coaly and graphitic forms, and making the rock black, slippery, and tender.

The borings show that the contact between the granite and schist is an approximately straight line, extending parallel with the axis of

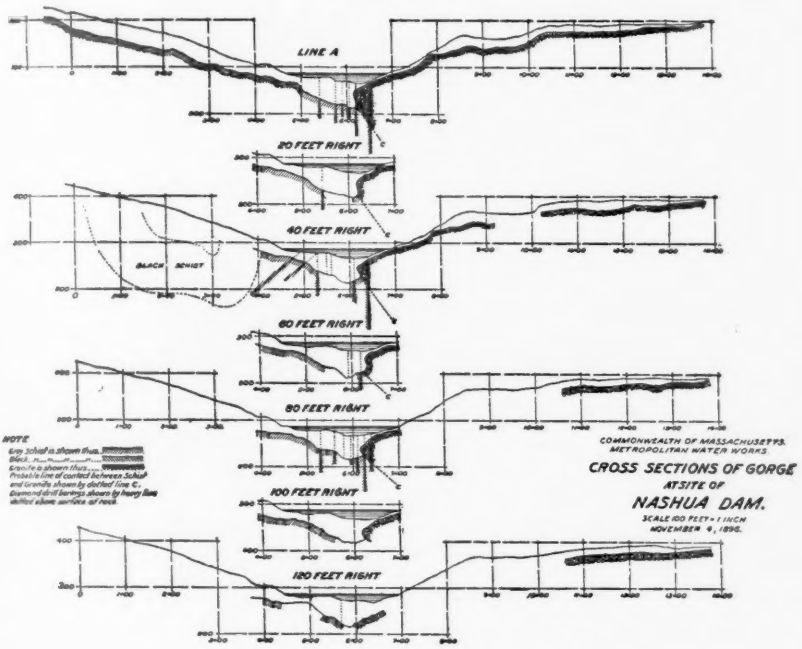


FIG. 6.

the river from about 6 + 20, 80 R, to 6 + 20, 80 L. (*C.* Figures 5, 6, 7, 8, and 9.) The diamond drill borings have also shown that the granite overlies the schist, nine different holes having passed through granite bed-rock into underlying slate, and in no case has granite been found below slate. This, together with the fact that the schist is reached at a greater depth in the more westerly holes, proves that the contact has a westerly dip. Fortunately, on each of four different profiles or cross-section lines — 80 R, center (A), 40 L, 80 L — two or more holes have passed through the granite into the schist, thus affording the data necessary to determine accurately the dip of the

contact. This is found to be in the main quite regular, all the determinations falling between 40° and 60°, and all but one (40 R) between 55° and 60°. A careful examination of all the cores near the line of contact shows that this is also the normal dip of the slate, the granite having forced its way up through the slate parallel with the bedding of the latter, an original plane of weakness having been determined here by a thin bed of the highly carbonaceous (coaly and graphitic) slate with streaks and partings of the gray slate. The more easterly borings, and especially the tunnel, showed, however, great variations in the dip of the schist, the bedding being almost horizontal at some points and nearly vertical at others, but always to the west. These marked variations of the dip are found to occur chiefly in the soft,

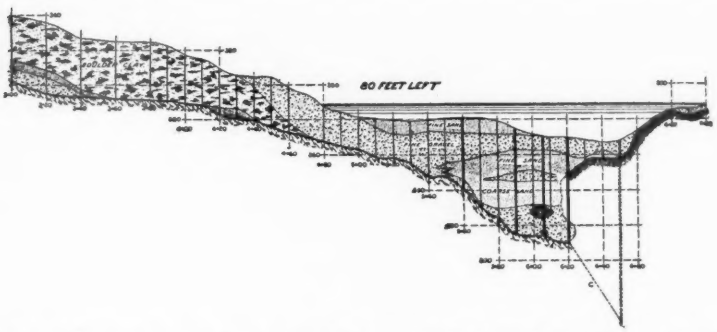


FIG. 7. — PROFILE OF THE SITE OF THE WACHUSETT DAM AT 80 FEET LEFT. (South.)

carbonaceous schist, which has yielded most readily to the bending and shearing stresses to which the formation has evidently been subjected.

In the ledges along the west bank of the river, the lamination or foliation of the granite is seen to have the same westerly dip as the contact of the granite and schist. This is clearly an igneous contact, and not due principally to faulting. This is proved by the facts that the granite incloses fragments of the slate, that it is shown by several of the cores to be firmly welded to the slate, and that it shows the normal gradation in texture, being usually very fine-grained next the slate, becoming coarser away from it, and coarsely porphyritic at a moderate distance.

The stream which excavated the buried gorge over which the Nashua now flows evidently tended to follow down the sloping contact of the granite and slate, the contact layer of carbonaceous slate offering a special inducement for it to do so. The geological condi-

tions were thus extremely favorable to the undercutting of the granite, and the development of a very unsymmetrical profile, a gently sloping eastern wall of schist, and an abrupt or overhanging western wall of granite. The precipitous character of the granite wall is proved by the very unequal depths of the bed-rock surface in closely adjacent

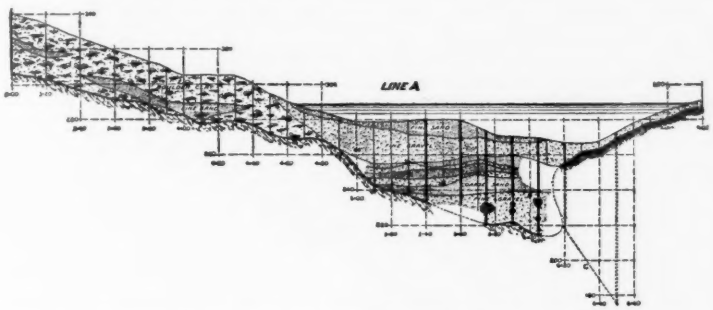


FIG. 8. — PROFILE OF THE SITE OF THE WACHUSETT DAM AT LINE *A*. (Center.)

borings on opposite sides of this line, and also by the character of the cores from several of the diamond drill holes in the granite, especially center line 6 + 20, 40 L 6 + 20, and 80 L 6 + 20. In these cases the drill penetrated the granite for 36.5, 44.4, and 27.0 feet, respectively, and yet through almost these entire thicknesses the granite is

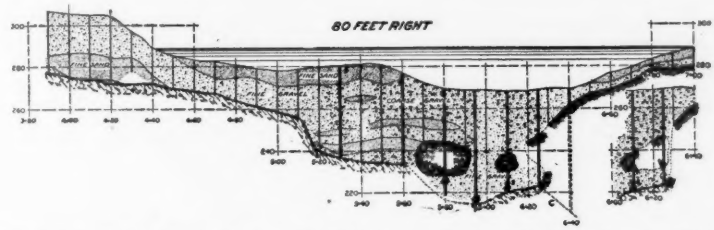


FIG. 9. — PROFILE OF THE SITE OF THE WACHUSETT DAM AT 80 FEET RIGHT. (North.)

rusty and weathered, especially along the joint cracks, indicating quite plainly that the holes were bored only a few feet back from the weathered face of a cliff or very abrupt slope.

Doubtless the most surprising fact developed by the diamond drill borings is the occurrence of gravel below the granite in a number of instances. Several of these have proved, when carefully plotted on the sections, to be probable bowlders. This interpretation is possibly applicable at 60 R 6 + 20, and 80 R 6 + 25, the alternative hypothe-

ses being expressed in the sections, but not at 80 L 6 + 20, where the drill passed through 27 feet of granite, the upper surface of which agrees closely with all the other profiles, since it would require us to imagine a long narrow bowlder poised on its end. The most natural explanation of this phenomenon seems to be this: The stream which formerly occupied and made this gorge, working down along the contact of the granite and schist, and acting laterally as well as vertically on the bed-rock, has undercut the granite to a moderate distance, several feet or yards, back from the face of the granite wall. Under the circumstances it would be very surprising if some undercutting had not occurred. That the undercutting is not very extensive is indicated by the failure to find the gravel in 40 L 6 + 20, although this boring crossed the level, and the geological position (contact of granite and slate) at which the gravel occurs in the other borings. The boring at 6 + 20 center line (*A*) apparently just misses an undercut at the base of the cliff, the 3-inch seam of sand at elevation 225 probably filling a widened joint crack extending a few inches back from the face of the ledge. The undercutting of the cliff appears so natural and almost inevitable that it has been indicated in some degree on all the sections.

The undercutting of the granite cliff, together with the joint structure of the granite, presents conditions extremely favorable to the detachment of large masses of granite; and several such undoubted bowlders are shown in the sections, the largest being 15 to 20 feet thick, and 20 to 30 feet long. The wash drill borings have isolated these masses, and the diamond drill has passed through them into underlying gravel, fully demonstrating that they are bowlders. The horizontal continuity of the longer ones might seem open to question; but it is required by the consideration that the horizontal diameter would naturally exceed the vertical.

A comparison of the sections shows that the granite cliff diminishes in height both northward and southward, holding its full or maximum height from about 40 right to 80 left, or 120 feet. The bowlders evidently diminish in size and number southward, and they are found wholly in a mass of gravel filling the bottom of the gorge. The upper surface of this bowlder-bearing gravel descends southward from about elevation 240 to 220. It is also very noticeable that the overlying deposit of modified drift, 30 to 50 feet in thickness, becomes finer southward, gravel greatly predominating in the northern sections and sand in the southern. Again the sections show that the bottom of

the gorge also slopes southward, the lowest level of the bed-rock surface definitely determined being 210 feet by the diamond drill boring at 80 left, 6 + 20. On line *A* the lowest point cannot fall much below 215, and on the line 80 right 215 feet is quite certainly the minimum elevation. The gorge also becomes narrower and more gorge-like southward.

All these facts agree in indicating that this gorge must have been excavated and filled by southward-flowing currents, and hence not by the Nashua, which now flows through this valley in the opposite direction. The surface bed of fine sand, 5 to 10 feet thick, probably once extended across the valley; and the excavation of its channel in this material is the only geological work that can be credited to the Nashua River flowing along this line. Its failure to cut deeper into these loose deposits is explained by the fact that at the dam of the Lancaster Mills, half a mile below (northward), it flows over a ledge of granite. The general distribution of the outcrops in this part of the valley, and all the topographic features, are favorable to the view that the buried gorge dies out northward, and that from this amphitheater of abrupt and rocky slopes encircling the Lancaster Mills and mill pond, a similar buried gorge probably trends northward, the dam of the Lancaster Mills resting on the water parting or dividing ridge of the two glens.

It is interesting to note in this connection that in some of the North Dike borings, north of Sandy Pond, the bed-rock has been reached only at a depth or grade fully 100 feet lower than the lowest point on the dam site. This fact confirms in the most conclusive manner the view that the Nashua River is now out of its preglacial channel, which lies a mile to the west of the dam site, and flowing at a level nearly or quite 175 feet higher. In preglacial times a small tributary probably started from near the present site of the Lancaster Mills, and flowed first south and then west to join the Nashua near the present site of Sandy Pond. The drift deposits left by the great ice sheet so completely filled and blocked the main valley that the river was forced to flow up the valley of one of its tributaries, and over the divide into the valley of a northward-flowing tributary. This means that no higher bed-rock foundation for the dam could probably be found in the course of the Nashua River.

The sections on a scale of 100 feet show the general relations of the gorge to the valley, and give only the diamond drill borings, and the depths to which they have penetrated the bed-rock, the deepest hole, at 60 L 5 + 00, extending about 30 feet below sea level.

STRUCTURAL DETAILS OF THE WACHUSETT AQUEDUCT TUNNEL.[1]

Besides the thin layer of carbonaceous slate along the granite-slate contact, occasional streaks and limited patches of it occur in and blend with the normal gray slate, before we come to the great development of this rock on the east side of the valley indicated by the borings, and fully proved later by the excavation of the tunnel. Shaft 1 of the tunnel (1 + 85) is in the gray phyllites which are here obscurely bedded with many slickensides. Between the shaft and the river the borings show fully 100 feet of the black graphitic slate, and immediately east of the shaft the tunnel enters a very typical development of the same rock, in which it continues without interruption for nearly 200 feet. Between stations 3 + 70 and 4 + 40 more or less gray slate alternates with the black; but beyond this the black slate is practically continuous for 200 feet more, and then gradually gives way to the gray phyllites. The black slate is throughout graphitic, and much affected by slickensides; and it is often, also, more or less tender and coaly. Pyrite is sometimes a conspicuous constituent, but as a rule it occurs sparingly or is wholly wanting.

The dip of the black slate is always to the northwest, but often indistinct, owing to the broken and chaotic condition of the formation. Starting from the shaft, it is low (30° or less) to 2 + 60, then high (70° or more) to 4 + 60, then low again (40° or less) to 5 + 60, and then gradually steepens to 80° and more. That the low dips between the shaft and 2 + 60 mark a synclinal axis, as indicated on the dam section for 40 R, is reasonably certain, especially in view of the fact that the deep, inclined diamond drill hole at 5 + 00, 40 R, although penetrating to 3 + 80 at grade 190, is wholly in the gray rock, except a small amount of black slate with quartzite near the top of the hole. This seems to show at least that the black slate does not dip down beneath the river, and the only alternative is to connect the two bands beneath the shaft. The sections of the dam site were drawn before the tunnel had passed through the black slate; but it now appears probable that the steeply dipping complex of black and gray slate between 2 + 60 and 4 + 60 marks a sharp anticline, followed on the

[1] Measurements in the tunnel, and the east-west measurements of the dam site run in opposite directions, and overlap somewhat, the starting point or station 0 + 00 for the tunnel being station 4 + 95 for the dam site, or about 125 feet east of the granite-slate contact, and near the east bank of the river.

east by a second syncline similar to the first. Although the advantageous position of the deep, inclined diamond drill holes was not fully foreseen, they are fully justified by the neat way in which, as it were, they head off the black slate, although it may be added that the vertical hole over 300 feet deep 100 feet south of this, at station 5 + 00 60 L, strongly corroborates the testimony of the inclined holes. From what precedes, it appears that all the observed facts of the dam and tunnel sections find a consistent and natural explanation in the assumption that one principal bed of carbonaceous slate is involved, with the underlying and overlying gray slate or phyllite in which are occasional carbonaceous patches and layers, in a closed and double synclinal fold, with its axial planes dipping steeply to the northwest.

The last trace of graphitic slate was observed in the tunnel at 6 + 80. Beyond that is a distinctly bedded, typical, gray sericite schist with quartzose bands and passing into a true mica schist as it approaches the granite. The dip is northwest 60°–90°, and undulating, or in part minutely wavy. At 7 + 58, where the dip is northwest 80° +, a very marked crushed zone 6 to 8 inches wide and parallel with the bedding crosses the tunnel about at right angles. This is a very obvious fault between the schist and the finely foliated or schistose granite. This important contact is now concealed by brickwork. The hard and solid distinctly

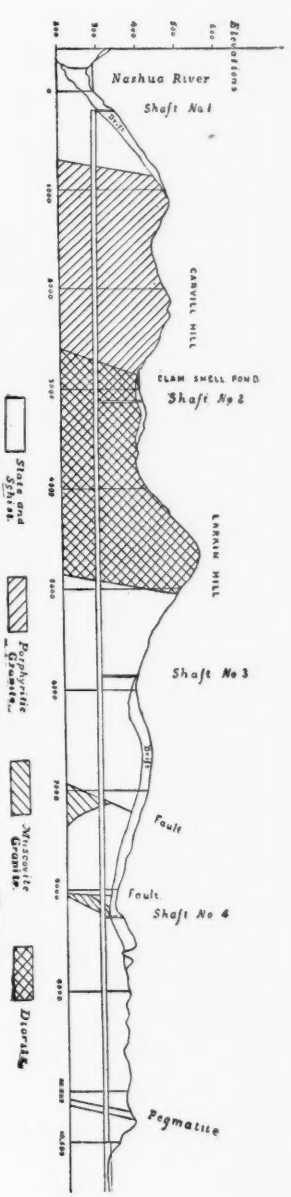


FIG. 10. — LONGITUDINAL SECTION THROUGH THE WACHUSETT AQUEDUCT TUNNEL.

and finely gneissoid granite, dipping northwest 80°–90°, and somewhat wavy, is continuous from 7 + 58 to 8 + 27. Between 8 + 27 and 8 + 45 the rock is a hard and massive but wavy mica schist, with the same dip as the granite, and firmly united to the granite on both sides in apparent igneous contacts. At 8 + 42 this inclusion of schist is broken by a strongly marked and very wet fault fissure which crosses the tunnel at right angles and hades with the dip. The schist shows much disturbance here, and is partly crushed. Irregular bunches of quartz occur in the fault, and also in the granite and schist between 8 + 10 and 8 + 30. Beyond 8 + 45 the laminated gneissoid structure of the granite, dipping northwest 70°–80°, becomes gradually less fine and distinct. Near 9 + 25 the porphyritic structure first attracts attention, and beyond 9 + 75 the normal coarsely porphyritic structure is well developed, except for a general parallelism of the phenocrysts, and aside from this, the rock is, as a rule, only coarsely and indistinctly laminated. At 9 + 60 a very marked and perfect shear zone and clay seam crosses the tunnel obliquely, and dips northwest 75°. It is 6 to 12 inches wide, perfectly plane and very wet — an ideal fault. Near station 10 + 10 another wet shear plane 1 to 4 inches wide crosses the tunnel obliquely and dips northwest 65°. At 10 + 82 a strong shear plane, open and wet, 4 to 12 inches wide and dipping northwest 75°, crosses the tunnel nearly at right angles. Another not so wide joins this obliquely, and a third crosses at 11 + 00 parallel with the first. Beyond 10 + 00 the granite is continuously very coarsely porphyritic; the gneissoid structure is indistinct or wanting, and prominent vertical dry joints cross the tunnel approximately at right angles every 5 to 10 feet for a long distance. Between 12 + 80 and 12 + 90 two of these joints are accompanied by clay seams and crushed zones. At 13 + 25 a mass of schist is inclosed in the granite. A strong and irregular clay seam and crushed zone crosses the tunnel at 14 + 00, dipping northwest about 60°. Through this part of the granite the gneissoid structure is marked chiefly by the parallel orientation of the great feldspar phenocrysts, which range from 1 to 5 inches in length. The high northwest dip diminishes rather gradually to 35° at 16 + 00. In the vicinity of 15 + 25 are several quartz veins 3 to 12 inches wide and 3 to 8 feet long, and approximately at right angles to the lamination of the granite. They are evidently segregated lenses filling cracks due to a stretching of the granite in the direction of its

lamination. At 16 + 25 a very wet seam or open joint crosses the tunnel, following the course of a large and irregular pegmatitic development of quartz, feldspar and chlorite (altered hornblende or biotite). Some masses of quartz are 1 to 2 feet in diameter, and the pegmatite blends with the inclosing granite. It forms one large irregular mass on the northwest wall 10 feet in diameter, and a vein 3 to 4 feet wide crosses the roof but does not reach the southwest side. The wet fissure dips northwest 45°, and on the southwest side of the tunnel takes the form of a crushed zone. At 17 + 55 to 65 is apparently another inclusion of fine and massive schist, which crosses the tunnel nearly at right angles as a layer 8 to 9 feet wide, and dipping northwest 50°–60°. The contacts are sharp and plain, and rather wet. Still other slabs of schist having the same dip occur in the granite near 18 + 00. At 22 + 10 a dike of fine granite cuts the porphyritic granite, and at 22 + 20 is a 3-feet vein of quartz dipping northwest 50°. The hanging wall of the vein shows movement, and is very wet. At 23 + 00 and 23 + 25 are inclusions of dark colored, massive schist, or possibly diorite. A more important body of schist — hard, quartzose, and very massive — extends from 24 + 13 to 24 + 37. The well-defined contacts dip northwest 45° to 70°, and are typically igneous, fragments of schist occurring in the granite and dikelets of granite in the schist; while the granite is non-porphyritic and finely gneissoid parallel with the contacts for a breadth of 5 feet. At 25 + 00 and 26 + 00 are inclosed masses of diorite, and at 26 + 10 is another mass of schist which extends to 26 + 20.

The coarsely porphyritic, massive and indistinctly gneissoid characters of the granite are practically uninterrupted for over 1,600 feet; but east of 26 + 00 the phenomena of the western border are repeated, and the porphyritic structure rapidly but gradually gives way to a fine and even foliation, the granite becoming at last almost indistinguishable from a true schist, as we near the contact with the diorite at 26 + 90. The dip is northwesterly, as before, but comparatively low, 30°–45°.

Between 24 + 30 and 25 + 30, but much more decidedly east of 26 + 30, the granite shows more or less decomposition, especially along prominent joint and shear planes, some of which are very wet. It is in part completely disintegrated and well advanced in kaolinization, recalling the rotten gneiss of the Hoosac Tunnel, and seeming to possess, like that, a special interest as an instance of deep-seated

decay dating in part, possibly, from preglacial times. In explanation of this phenomenon we may note that the granite is in general a very hard and rigid rock, and the joints, which are due to earthquake and other movements, are naturally more open than in the more yielding diorite and schists; and consequently this part of the tunnel, in the granite and below Clam Shell Pond, is extremely wet. This free and long continued circulation of surface waters through the granite is quite clearly the cause of the decomposition; and since it is probable that the decay will be somewhat accelerated by the more active circulation which the tunnel permits, a part of this ground has been lined with brickwork.

The contact of the granite and diorite, now concealed, crosses the floor of the tunnel near 26 + 80 and the roof near 27 + 00, dipping northwest about 30°. Although this is undoubtedly an igneous contact, due to the eruption of the granite through the diorite, movement has subsequently occurred along it, giving rise to a well-marked zone of crushing and shearing; and the passage of water through this broken material has caused more or less decomposition, especially of the granite.

Lithologically, the diorite is subject throughout to constant variations with the varying prominence of its secondary minerals — pyrite, biotite, chlorite, epidote, and calcite — the epidote and calcite occurring usually as distinct segregations and veinlets. East of the contact the diorite is indistinctly laminated or sheared parallel with the contact, northwest 30°–35°. At 27 + 30 is a strong shear plane and clay seam, and another at 27 + 80. Beyond 28 + 50 the rock becomes much more massive and solid, and so continues with occasional shear planes to shaft 2 (33 + 10).

For the first 600 feet east of shaft 2 the diorite is massive, and the lamination, where observable, dips northwest and north-northwest 45°–50°; while for a good part of the distance very regular joints hade (inclination to vertical) to the southeast 10°–15°. Between 35 + 70 and 90, a shear zone 6 to 12 inches wide dips northwest 45°, and at 36 + 00 is another. For about 250 feet beyond 37 + 30 the diorite is less solid and more affected by clay seams and crushed zones, and the principal joints dip north and north-northeast at high angles, the rock being completely sheeted by them at some points. The most conspicuous crushed zones are at 37 + 44, 37 + 80, and 39 + 60, dipping northwest as usual. Beyond this the diorite is somewhat quartzose

and very massive to 43 + 50, after which it is, in the main, strongly laminated and often shaly, the structure planes dipping north and north-northeast 70° to 85°, parallel with the diorite-schist contact, and so continues to the end.

The contact between the diorite and gritty schist is nearly vertical, and crosses the tunnel very obliquely, cutting the southwest wall at 48 + 80, and the northeast wall at 49 + 20; and in taking a general view of the structure of the diorite, no fact appears of greater significance than the conformity of the lamination (which must be, in the main at least, a secondary feature) with the diorite-granite contact in the western half of the belt, and with the diorite-schist contact in the eastern half of the belt. The chief evidence that the latter contact is igneous is found in the fact that the main contact is followed in the next hundred feet or so by several alternations of diorite and schist, suggesting dikes of diorite.

The massive and gritty schist presents few details of interest beyond what have been stated. In structure it varies continually from very massive to quite distinctly laminated or even shaly. The strike is usually approximately parallel to the tunnel (south 42° 30′ east) and the dip is northeast 60°–85°. Occasionally the strike varies to south 60° east, and in the vicinity of shaft 3, to south 70° east. Irregular veins and lenses of quartz are of frequent occurrence. Many of the principal joints tend to conform in direction with the stratification, giving the rock a platy structure, and at several points slipping along these planes has developed more or less distinct crushed or sheeted zones. One of these, about 2 feet wide, occurs between 51 + 50, and 51 + 80; and another 3 feet wide was noted at 58 + 35, near the shaft.

Beyond shaft 3 (58 + 55) the gritty schist gives way rapidly but not abruptly to the slaty schist, which is continuous to the muscovite granite at 70 + 60. This rock, which is usually free from pyrite, and rarely contains more than a trace, is very distinctly stratified; and the rock cleaves or separates very readily along the bedding planes into layers from an inch to several inches or a foot or more in thickness (slaty structure); but very frequently also it subdivides or splits up almost indefinitely, becoming highly fissile (shaly structure). These bedding planes are invariably very smooth, and even slippery, and are commonly striated or grooved in a definite direction, showing very plainly that differential movement or slipping of the beds has oc-

curred; and this movement, where most severe, has developed numerous crushed zones and clay seams. Similar movements, resulting in the smoothing, fluting or comminution of the rock, have occurred along the many prominent joint planes, of which there are usually two well-defined systems, one often vertical and the other inclined, and both intersecting the bedding planes. The strike of the bedding is approximately parallel to the line of the tunnel, usually bearing north of the tunnel from 0° to 20°, and the dip is steadily to the north-northeast, varying from 60° to 80°, but usually near 70°.

At 67 + 70 the strike is suddenly deflected to the north 20°, and beyond this the rock is much contorted and broken for 50 feet or more. Between 69 + 00 and 69 + 70, three strongly marked clay seams cross the tunnel in the bedding planes. They are very obvious faults. Between 70 + 40, and 70 + 50 the strike suddenly shifts again, to north 80° east, and from this point to the beginning of the muscovite granite, at 70 + 60, the rock is highly contorted and crushed.

The contact of the schist and granite crosses the tunnel at right angles and dips northwest 70°. It is distinctly igneous, the two rocks being firmly welded together; but near the granite the schist is much comminuted and very shaly, and shows two strong clay seams parallel with the contact, one about a foot from the granite, and the other 6 to 8 feet from the granite. It is very evident that this contact, although originally igneous, is now an important fault, the magnitude of the slip being indicated by the effect upon the dip and strike of the schist, and the sharp up-turning of the beds proves that the schist is on the down-throw side of the fault. The granite extends for about 105 feet along the southwest side of the tunnel, but for only 50 feet along the northeast side, the eastern contact of granite and schist cutting the tunnel very obliquely. The granite is evidently a jutting angle of the boss of Snake Hill, as the map indicates; and doubtless the tunnel would have missed it altogether had it been run a few yards farther north. The eastern contact appears to be essentially similar in history and character to the first — an igneous contact modified by a fault, but dipping northeast 80° instead of northwest 70°. The schist is in beds 2 to 12 inches thick, except near the contact with the granite, where it is very shaly for 2 to 3 feet, and more or less for 5 feet. The granite is normal throughout, the marginal gneissoid phase not being developed here.

East of the granite the micaceous slate continues essentially un-

changed, except that, the tunnel being here nearer the surface, a large proportion of the rock is distinctly oxidized or rusty (weathered) and tender or rotten in texture. The strike is in the main closely parallel with the tunnel, but varies both to the north and south of this line, as if the granite were near by on the south, and the dip is northeast 70° to nearly 90°. Crushed zones and clay seams of sensible thickness are not a prominent feature, but practically every bedding plane and every joint plane is a thin clay seam. They are remarkably smooth, striated in a definite direction, usually northwest at angles of 30° to 45° with the vertical, proving slipping, and coated with an impalpable clay due to this movement. At 73 + 10 a clay seam 2 to 8 inches wide dips east 15°.

At 80 + 62 an important and nearly vertical fault crosses the tunnel nearly at right angles. It is a very wet open fissure, and its great structural value is found in the fact that it marks a very abrupt general change in the strike of the schist. Northwest of the fault the strike is, as usual, parallel with the tunnel and the dip north 85°–90°, and the strata maintain this attitude right up to the fissure, while in the southeast wall of the fault the strike is parallel with the fissure (north-northeast) and the dip northwest 70°. On one side of this sharp line the strike follows the tunnel closely for 3,000 feet, and on the other side it is approximately at right angles to the tunnel for 2,500 feet and probably much farther.

The tunnel begins now to cross the strata, and they exhibit greater variety in consequence, layers of slaty quartzite first relieving the monotony of the series. At 81 + 60 the dip has increased to northwest 85°, and at 82 + 00 we come to the contact of the schist and the highly and finely laminated (gneissoid) muscovite granite. The contact is parallel with the foliation of the granite and bedding of the schist, and dips northwest 75°. The granite, still holding its gneissoid structure, continues to shaft 4 (83 + 12), where, near the bottom of the shaft, it is conformably underlain by the schist, dipping northwest 65°–70°. As previously noted, this narrow band of gneissoid granite is clearly a northward extension of that so well exposed on the Central Massachusetts Railroad, a great dike or branch from the parent boss. The brick lining of the tunnel is continuous from shaft 3 to shaft 4.

East of shaft 4 and the muscovite granite, the schist begins to be pyritiferous and graphitic. The graphitic character, with marked variations and slight interruptions, continues for 800 feet to 91 + 10, the

dip continuing steadily northwest 80°–85°. As the graphitic character fades out, a coarse biotite becomes more or less prominent in parts of the schist, these alternating with both quartzose and pyritiferous bands. Beyond 92 + 50 the schist becomes more solid and massive, and is rarely graphitic or decidedly pyritiferous; but it is commonly quartzose or biotitic. Between 93 + 85 and 93 + 90, a strongly marked crushed zone and clay seam parallel with the bedding, and 1 to 5 feet wide, crosses the tunnel. A vein of quartz 6 to 18 inches wide follows the south wall from 94 + 10 to 94 + 50. Beyond this, pyrite again becomes a prominent character in much of the schist, with some pyrrhotite and chalcopyrite, and continues to the end of the tunnel. East of 97 + 00 the schist again becomes somewhat graphitic as well as pyritiferous. At 97 + 35 is a strong and very wet clay seam. The 10 feet between 97 + 60 and 97 + 70 is about half quartz in large and small veins, the larger veins inclosing many angular fragments of the schist; and beyond this the schist is more or less veined with quartz and calcite to 98 + 00 and beyond. At 100 + 70 a crushed zone several feet wide crosses the tunnel; another at 102 + 70, and a clay seam at 103 + 90. At 100 + 80 the interbedded veins of pegmatite begin to appear, and the pegmatite is almost continuous from 101 + 00 to 101 + 50, appearing again at 103 + 10, and 103 + 90 to 104 + 00. At 101 + 40 a massive blue mineral thought to be fluorite adds variety and interest to the composition of the pegmatite. For the last 1,500 feet of the tunnel, and more or less all through the pyritiferous schists, the walls and roof were stained at intervals by bright orange-colored deposits of ferric hydrate (limonite) formed by infiltrating meteoric waters and indicating active oxidation of the pyrite. And for the last 250 feet, or as far as the conditions favored evaporation, the rock was whitened by an efflorescence of calcium and sodium sulphates, showing the potent influence of the oxidation products of the pyrite in decomposing the associated silicates. East of shaft 4 the dip is very constant, northwest 80°–90°.

General Conclusions.

In a general view of the geology of the tunnel, including also the dam site, two facts are especially prominent: (1) The normal strike (north-northeast to south-southwest) holds continuously west of the middle of the diorite, and east of station 80 + 62, while for the

intermediate distance of over 4,000 feet, following the line of the tunnel, the strike is transverse and nearly at right angles to the normal. (2) For the normal strike, all the important structure planes other than joints, including bedding planes, foliation and shear planes, crushed zones and faults, dip to the northwest, usually at high angles (30°–90°), while for the transverse strike the dip is constantly to the northeast, and always at high angles (60°–90°). The persistent northwesterly dip accompanying the normal strike is evidently a fact of great significance in its bearing upon the general structure of the Nashua Valley, but demanding for its full understanding and correlation a wider study than has been attempted here. As previously stated, the transverse strike appears to affect the formations for only a moderate distance northward from the muscovite granite; and it is evidently related to the sudden appearance of this boss athwart the dominant trend. The general structure is clearly such as would result from an important fault along the northern border of the muscovite granite with the downthrow to the north, and causing by its drag a sharp upward flexure of the schist and the diorite. Although not clearly expressed on the map, this great displacement is proposed provisionally as the best general interpretation of the structure. The faults so clearly and closely bordering the muscovite granite between 70 + 60 and 71 + 60 in the tunnel have precisely this influence upon the structure of the adjacent schist, and they are regarded merely as local phases or expressions of the main displacement.

Throughout the tunnel the joint structure is usually well developed, and commonly in two approximately rectangular systems which show a marked tendency to be normal to the shearing and bedding planes, suggesting that the joints should, perhaps, be regarded as tension cracks developed during the plication and shearing of the rocks. It is certainly noteworthy that in an area where the rocks are so thoroughly sheared, faulted, and jointed, dikes or any igneous intrusions of later date than the plutonics should be entirely wanting; but such appears to be the case.

That the lamination or foliation of the diorite is chiefly and of the granites partly a secondary structure due to shearing stresses originating in a transverse compression of the formations, is reasonably certain. The remarkably perfect marginal gneissic structure of the granites, on the other hand, is, in my opinion, best regarded as an original structure due to the drag of the stiffly viscous granite magma along

its walls during its intrusion into the schist and diorite. In fact, this structure appears to find a perfect explanation in the not unreasonable assumption that the magma continued to flow not only after the formation of the phenocrysts, but after the ground mass itself began to stiffen and harden. This explanation accounts equally well for the general, but often imperfect, parallelism of the phenocrysts with the walls throughout the entire thickness of the porphyritic granite, and for the fact that the gneissic structure is in both granites most strongly marked near the walls, and becomes rapidly less perfect away from the walls. The still plastic quartz was drawn out like half molten glass into thin sheets and lenses, while the feldspar phenocrysts were stretched, broken and dragged out, suffering by virtue of the high temperature and pressure in the presence of water plastic as well as clastic deformation.

Both the quartz and feldspar of the ground mass, but especially the former, show the fluidal elongation more or less throughout the granite. In short, the whole gneissic character of the granites, with the exception of certain shear planes, may be regarded as flow structure, sharply accentuated, as flow structure should be, along the borders of the granite. Even where most finely and perfectly developed, this true gneissic structure does not render the granite notably schistose or fissile, but it is still a firm, solid rock.

According to the alternative hypothesis, the gneissic structure is secondary, the product of compressive stresses and consequent shearing, or plastic flow, if the rocks were, as we may suppose, in the zone of flow. This view fails to explain the marginal localization of the more perfect phases of the structure; and furthermore, the true shearing, like close jointing, not only renders the rock fissile, but it is somewhat uniformly distributed through both the granite and diorite. Original flow structure is especially characteristic of acid magmas; while the granites being decidedly the most rigid of all the rocks of this region except the quartzites, and these are not generally foliated, should according to the compression hypothesis, be throughout of exceptionally massive structure. But in reality they are, marginally, as highly foliated as almost any of the schists, and much more so than a large part of the schist series.

DIESEL'S RATIONAL HEAT MOTOR.

By E. D. MEIER, C. E. and M. E.

Read February 23, 1899.

Many of my audience will, no doubt, feel that I am stating a truism when I preface my remarks by saying that all the power which man uses is derived, in a more or less direct manner, from the heat of the sun. For many centuries animal or muscular force, and the simplest applications of wind and water power, sufficed to fill the modest requirements of the human race. It is true that priestcraft, which seems to have been the earliest modification or check on the rule of might, did use direct heat as a force for performing some simple operations, such as the speaking or singing of hollow statues, or the moving of temple doors, all enveloped in mystery, partly because the authors themselves could not explain them, and partly because this mystery was a bulwark of defense against the crude force of the warrior. And somewhat later, the first engineer that we know of, Hero of Alexandria, did build and operate the first steam turbine.

But centuries passed again before even the wisest and most imaginative men began to appreciate the vast consequences and the great advantages which would follow the practical utilization of the direct force of heat. Even war, the delight, the sport, and the sole support of kings and nobles, was slow in utilizing the tremendous force of suddenly liberated heat. And then cannons and muskets had been used for nearly three centuries before any one thought of applying the tremendous energy of expanding gases to the useful arts; and when it was done the effects only were studied, no one even suspecting the cause. Towards the end of the seventeenth century we come upon a period of experimentation.

The Marquis of Worcester, in 1663, forced water to what was for the time an unprecedented height, about 40 feet, by the expansive force of steam, while Huyghens in 1680, and Papin in 1690, attempted

to produce motion and power through the explosive force of gunpowder, and again in 1698 Savery used steam in what we may consider the original pulsometer pump.

Nearly a full century passed before Watt, in 1769, succeeded in harnessing the expansive force of steam, and almost at the same time Street (in 1791) succeeded in moving an engine by exploding the vapor of turpentine in the cylinder. We see, then, that the beginnings of the steam engine and the internal combustion engine fall into about the same period. Neither of these experimenters and inventors recognized heat as being the primal potential energy which he was trying to utilize. Had this been done at that early period, it is more than likely that the vast industrial development of the nineteenth century, with all the myriad blessings it has conferred upon humanity, would have been retarded, or possibly even delayed for a number of decades. For if heat had been recognized as the prime mover, it is very probable that the bulk of the work of experimenting and invention would have been directed toward the internal combustion engine. But there was then no chance of success for this really more rational type. The steam engine with its many inherent defects and its wasteful cycle had to precede and break the way, just as the ox team of 1849 preceded the Pacific railways of 1865.

A clear knowledge of cause and effect would have compelled fair reasoners to decide that the heat should be produced at the very point where it is to be utilized. But neither materials, lubricants, tools, or skill were then available to harness this mighty force in its naked strength. Steam presented one great advantage over all competitors, that it could be used at very low pressures, such as the means at hand were sufficient and ample to contain and utilize. From the 8 pound pressures of the early Atlantic steamers, or of the wooden boilers of the Fairmount Water Works, to the 200 pounds and over of the present ocean greyhounds and the latest Leavitt pumping engine, is indeed a far cry; and this distance had to be covered by the slow plodding and groping industry of millions of men, each generation advancing slowly, but building on the work of its predecessors, gaining a knowledge of metals, learning how to vary and improve their properties, constructing better furnaces, forges and rolling mills, gradually advancing from the cold-riveted cylinder boiler of fifty years ago to the best types of Scotch marine, the locomotive, and water tube boilers of to-day, built with power rolls, flanging presses, and hydraulic riveters.

From the clickety-clack Cornish bull engine, painfully and slowly raising its ponderous piston to the top, and then dropping down with a crash and bang at perhaps thirty strokes a minute, to the noiseless Worthington pump of to-day, with a coin balanced on its cylinder head for hours while doing full duty; from Stephenson's "Rocket" with its twelve miles an hour over a rough track forty miles long, to the great ten-wheeler of to-day, carrying palace cars over smooth 100-pound rails across our continent in less than four days; from Watts's engine, requiring 62 pounds of water and 8 pounds of coal per HP. an hour to the triple-expansion engines of your modern cotton mills, consuming but 11 pounds of one, and $1\frac{1}{4}$ pounds of the other; from the tallow melted in a tin can on the cylinder head, to the union pressure oiler of to-day, which forces its 600° fire test oil with precision to the very spot wanted, and with just the requisite number of drops per minute; from the laminated boiler plate of fifty years ago, crude conglomerate of cinder and iron, mixed no one knew how, to the flange steel of to-day, with its exact constituents of carbon, of sulphur and phosphorus fixed by contract in advance; from the breast drill of our forefathers to our boring mill and turret lathe, — in one word, from the threshold of the nineteenth to the threshold of the twentieth century, the steam engine, and those who served it, have done a work for humanity worthy of greater epics than Homer's or Virgil's, of mightier brushes than Raphael's or Meissonier's; for the great song of steam is yet unsung.

It is, therefore, a bold word to prophesy that this true king of the nineteenth century is in danger of being dethroned, and his successor ready to take up his burden. Yet men like Rankine, Fleeming Jenkin, Redtenbacher, and Zeuner have been predicting this for some years, and our own Thurston has but recently fixed the exact limits to which further progress in the steam engine must of necessity be confined. He says: "With equally excellent design, construction, and management, we may expect the efficiency of the steam engine with increasing pressures to increase nearly as the logarithm for the boiler pressure."

According to this, if we can count in practice on 13 per cent. absolute efficiency with steam at 200 pounds, $15\frac{1}{2}$ per cent. would be the limit at 500 pounds, and 17 per cent. at 1,000 pounds steam pressure. And in this reasoning the increasing difficulties of steam production and boiler economy at a higher pressure have not been considered. This shows what has been done after a century of experimenting, and

another century of most careful, well-directed, and even brilliant effort on the part of many men of genius.

The long line of analysis which brings out these conclusions may be said to have begun when, 101 years ago, a Yankee engineer, Benjamin Thompson (Count Rumford), imparted the discovery made by him in the cannon foundry at Munich, Bavaria, that "heat is not matter, but a form of energy." Other experimenters followed, but it was not until much later that Joule, in England, and Mayer, in Germany, determined and fixed the mechanical equivalent of heat. Early in this century, Sadi Carnot in France developed the theory of a perfect heat engine. Yet it was a long time before the clear reasoning of these men, although enthusiastically received and elaborated by scientific engineers in Europe and America, found its way into the designing room of engine builders. For a long time the steam engine was studied only in its mechanical aspects, and the striking success of Corliss, while a great stride toward mechanical perfection, tended rather to retard than to accelerate the study of the steam engine as a heat motor. Hirn's work at Mulhouse, Professor Lanza's work here in Boston, and Isherwood's practical experiments, finally roused mechanical engineers to the importance of considering the utilization and conservation of heat in the steam engine as the fundamental question of design. Even Ericsson, one of the pioneers of the steam engine, had previously turned to the hot-air engine to escape from those losses inseparable from the employment of steam. Naturally enough, then, many scientists and inventors turned again to the internal combustion engine, which had been previously experimentally developed by Barnet in England, Drake in America, LeNoir in France, improved by Brayton, Barsanti, and others, ably discussed and advocated by Dr. Siemens, and finally developed into a practical working machine by Otto in 1876.

Otto's master patent, though at first vehemently attacked, became the foundation on which Priestman, Crossley, Atkinson, Capitaine, Clerk, and others, built up a number of types with a gradual and satisfactory increase in economy. But they all worked in the beaten path of mixing a charge of gas and air, carefully compressing it, and igniting it for explosive action by various igniting devices. No one attempted a vital change in the cycle itself until Rudolph Diesel, in 1893, proclaimed his method and attempted the development of a practical working engine on the beautiful ideal of Carnot. After ex-

perimenting with various vapors more permanent than steam, and at first attempting both to add and withdraw the heat from the working fluid from without, he reached the conclusion that the atmosphere about us would furnish a cheap, endless supply of a permanent gas, available not only as the vehicle of heat, but as the means of evolving it from the fuel employed.

Rudolph Diesel is a Bavarian, forty years old. He received his early education in Paris, where his parents then resided, until they were forced to emigrate in 1870 by the decree of the moribund empire. He is a man of studious habits, a good mathematician and thoroughly versed in the science of thermo-dynamics, which he has made his life study. As a student at Munich he was a pupil of the celebrated Professor Linde, now well known as the inventor and builder of the excellent ice machine which bears his name. Since the publication of his lecture of June 16, 1897, he has been fairly overwhelmed with praise and congratulations by the leading professionals of Europe. Perhaps no better gauge of the strong common sense and real greatness of the man can be found than the fact that all this praise and adulation have not turned his head in the least. He remains the same simple, earnest, conscientious student that he was before his great invention dazzled the experts in his line of engineering.

I was particularly struck with the simplicity, and I might almost say humility, with which he spoke of his great achievements. He considers his present success only as an incentive and a stepping-stone to further work and progress. He is very accurate in all his statements, and thoroughly honest. Nothing can induce him to confound even his most sanguine hopes with a promise of any future success. He patiently and good humoredly answered all my questions, and was instantly ready to show me authorities for his statements from the carefully chosen books of his extensive library.

As an engineer he is more theoretical than practical, but has now at his command some of the best practical talent of Germany. Professionally well equipped and clear in his ideas, he is so simple and amiable in his manner that it is a pleasure to work with him, and these characteristics of the man promise to make the working together of the various interests in the many countries in which he has issued licenses satisfactory and beneficial to all, and will make a rapid progress in the practical development of the invention possible.

Mr. Diesel has been at work on the theories on which this motor

is constructed ever since he was a student at the Munich Polytechnic School. For the past fifteen years he has devoted himself almost entirely to this work. He even built a small experimental motor in Paris many years ago, the working of which enabled him to modify his first theories considerably. He, however, took the precaution to have the parts of this motor made in different shops to prevent his ideas and processes from becoming known. In 1892 he made his applications for his first patents in different countries.

When his book was published it hardly went farther than into the libraries and studies of men specially interested in the theory of thermo-dynamics. But Mr. Buz, of Augsburg, the general manager of the great machine works there, placed means and men at the disposal of Mr. Diesel, to enable him to work out his theory in practice, and a 12 horse-power motor was built there, on which many experiments were made. The improvements suggested were embodied in a second machine of the same size, and from this was evolved the 20 horse-power motor which established the working type now adopted. Mr. Fr. Krupp, of Essen, the German steel king, also became interested in the matter. Mr. Diesel moved to Munich so as to be able to give his whole time to this work.

In the meantime, in 1895, a Mr. Schmidt, of Cassel, worked out and exhibited a steam engine working with highly super-heated steam. For the time this motor attracted the attention of the engineering world. Its defects were, however, so apparent that it did not come into general use, but it did serve to withdraw attention from Diesel and his work. On the 16th of June, 1897, Mr. Diesel delivered a lecture before the National Society of German Engineers at Cassel, in which he not only developed his theories, but exhibited in drawings the actual construction of his motor, and gave some data in regard to practical results obtained at Augsburg. Professor M. Schroeter followed Diesel in further development of the theory of the motor, and gave in detail the results of tests made by him on the first experimental motor, and stated his conviction that the motor was now ready for commercial work. (These essays were published in the "Zeitschrift des Vereins Deutscher Ingenieure" of July 10, 17, and 24, 1897.)

At the conclusion of these papers a wave of enthusiasm swept over the large audience of professional engineers, and the desire naturally arose to see the motor at work. Mr. Diesel extended invitations

to all engineers and manufacturers to visit the works at Augsburg and to examine and test the motor for themselves. This invitation had been so generally accepted, that for the next nine months the motor was practically on exhibit for every hour of the day, under the closest inspection by engineers, not only from Germany, but from every civilized country. It was therefore necessary to keep it running as a petroleum motor, and not until April, 1898, was it possible to dismantle the engine in order to make the slight but important changes to adapt it to experimental work on gas.

Mr. Diesel's idea was to follow Carnot's cycle strictly, obtaining the lower isothermal and adiabatic curves by compression, and the upper ones by combustion and expansion. For a long time he experimented with various vapors, which, under normal conditions, are far above their points of condensation.

Ammonia vapors, especially, seem to have the properties best suited to the theoretical process. But great difficulties in handling them were encountered in practice. In the endeavor to replace them he was naturally led to experiment with air. Up to this time he had necessarily applied his heat from without, and was subjected to the losses and limitations due to the metal walls through which it had to pass. He was then subject to the same losses which had defeated Ericsson, and was compelled to make the step which made his motor an internal combustion engine. Starting out, then, with the intention of improving the caloric process of the steam engine, he reached, in a round-about way, means similar to those employed in gas and oil engines. But this similarity is strictly limited to the *fact* of internal combustion, the *method* of combustion being radically different. Further, finding that to begin his compression isothermally led him into pressures which must, in our present practice, be considered excessive, he abandoned that part of the Carnot cycle and made his compression adiabatic throughout, thus reducing the necessary pressures from over 100 atmospheres to between 30 and 40. When, as in the history of the steam engine, these higher pressures become practically feasible, a return to the original complete process may become advisable. Mr. Diesel's fundamental invention is then really a process for converting heat into work; this, of course, has been supplemented by other inventions naturally growing out of the persistent and logical development of a practical machine to operate on this process.

It was Diesel's first intention to build a motor with three cylinders,

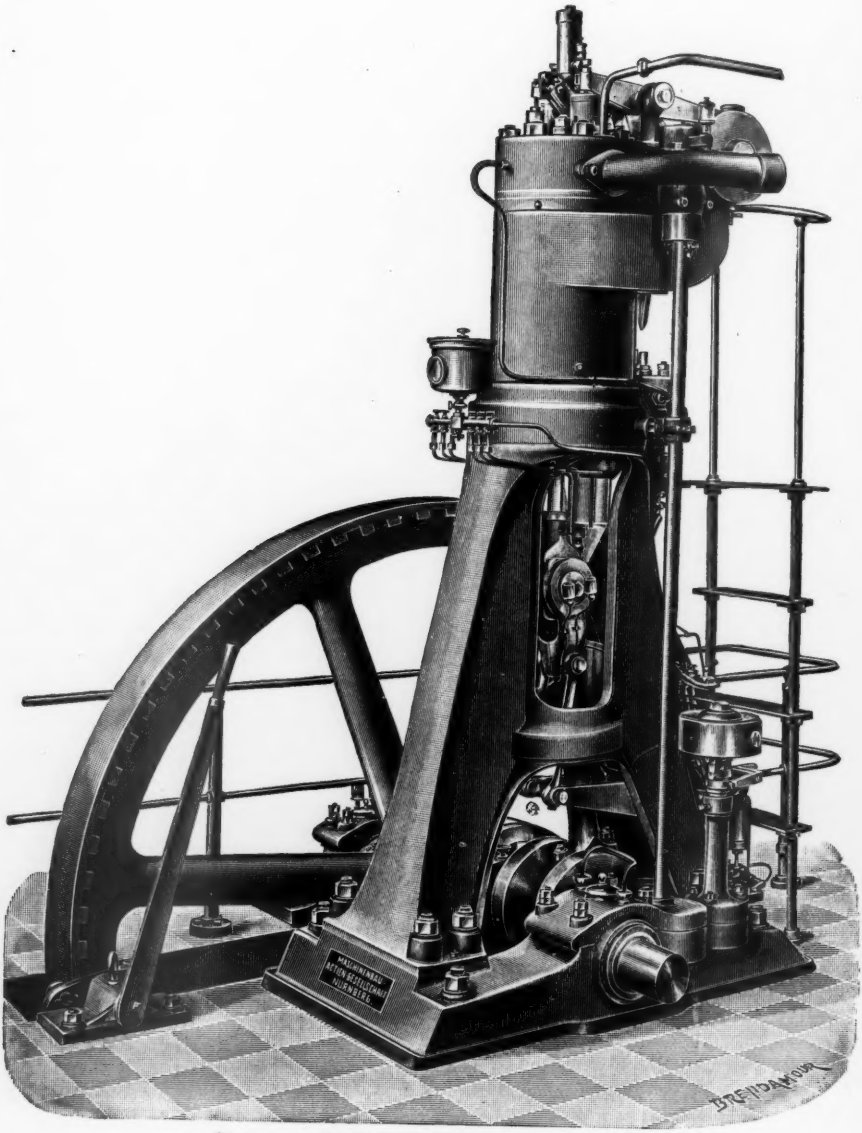


FIG. 2.—20 H. P. DIESEL MOTOR, GERMAN TYPE.

embodying compound compression and compound expansion, and one of this type has been built at Augsburg, and is to be thoroughly tested on producer gas. But the development of the single cylinder type has been so satisfactory, and the demand for them has become so great, that at present the German shops are busy to their fullest extent, building this simpler form. As this form has reached an absolute efficiency of 30 per cent., and is in every way a simple and practical machine, there is at present no reason for developing the compound motor. The cut here given (Figure 2) represents the first of these 20 HP motors, built by the Nuremberg Machine Works. This motor was exhibited at the Electrical Exposition in New York City, held in May, 1898. In appearance it resembles a vertical marine engine. A strong base plate supports the main journals of the crank shaft, outboard bearings being provided for the shaft extensions which carry the fly-wheel and pulley. Bolted to the base plate is a stout *A*-frame containing the guides. In the rear leg of this frame a small air pump is supported. On the top of the frame is placed a cylinder open at bottom. Its top is closed by a head cast in one piece, in which are contained one suction valve for air, one discharge valve for spent gases, and a needle valve for the fuel. The admission to the casing of this fuel valve is controlled by a stop valve which can be instantly closed to shut off the supply of fuel. Besides this, there is a starting valve used only in starting the engine. Cylinder and air pump are water-jacketed. This water jacket was not used in the earlier experimental engines, but is found advantageous in keeping the temperature of the working parts uniform. As the temperature of combustion is so much lower than that of the explosion type of engines, a much smaller amount of water suffices for this. In the earlier German engines the main shaft and crank are bored for water cooling. This, however, grew out of the practice of Krupp's Steel Works of boring all small shafts produced. The practice has been discarded in England and in America as unnecessary. The air pump is driven by a set of levers attached to the main cross-head. Conveniently placed to one side is an air vessel known as the starting tank, connected by copper pipe to the air pump, and to the fuel valve casing.

The operation is as follows: On one down stroke the main cylinder is completely filled with pure air; the next up stroke compresses this to about 35 atmospheres, creating a temperature more than sufficient to ignite the fuel. At the beginning of the next down stroke

the fuel valve opens, and the petroleum, atomized by passing through a spool of fine wire netting, is injected during a predetermined part of the stroke into this red-hot air, resulting in combustion controlled as to pressure and temperature. This injection is made possible by the air in the starting tank, which is kept by the small air pump at a pressure some 5 to 10 atmospheres greater than that in the main cylinder. A small quantity of this air enters with the fuel charge, which it atomizes as described. When the motor is running at full load a very small quantity of injected air suffices, and the pressure in the air tank steadily rises. At half load, with less fuel injected, more air passes in. For this reason, the starting tank is made large enough to equalize these differences, and a small safety valve is provided on the air pump.

The petroleum is pumped into the fuel valve casing by a small oil pump bolted to the base plate. This pump is arranged to pump a fixed maximum quantity of petroleum. A by-pass is provided so that this whole quantity, or any portion of it, can be returned to the supply tank. The governor controls the action of this by-pass valve, closing it just long enough to compel the exact quantity of the fuel required to pass into the fuel valve casing. As this requires only the movement of a small light wedge, the regulation is accomplished with great exactness. In this regulation resides a great advantage for the Diesel motor. The full charge of air being always supplied for complete combustion, it matters not whether the governor permits one or fifty drops of petroleum to enter the working cylinder at each motor stroke; the combustion is always complete. Thus variations in excess of air over that theoretically necessary, from 26 to 116 per cent., have been measured, and the analysis of the spent gases shows no trace of unburnt carbon or hydrogen. It is hard to conceive a more perfect combustion than that which takes place when fuel is sprayed, finely powdered or atomized into red-hot air, just beginning to expand. To stop the motor it is only necessary to close the valve which admits the petroleum into the fuel valve casing. The valve gear consists of a series of cams placed on a shaft journaled on brackets cast on the cylinder.

In starting the motor a hand lever is pulled to one side, throwing all these cams, except the exhaust valve cam, out of gear, and throwing a special cam into gear with the starting valve. A few strokes of the petroleum pump by a hand lever inject a small quantity of petro-

leum into the fuel valve casing. The fly-wheel is thrown over by a lever a trifle beyond the upper dead point. The fuel throttle valve is opened, and by a turn of the hand wheel communication is established between the air tank and the starting valve. A single charge of highly compressed cold air enters the cylinder, sufficient to give two revolutions of the fly-wheel at moderate speed. At the close of the first revolution the starting valve cam is automatically thrown out of, and

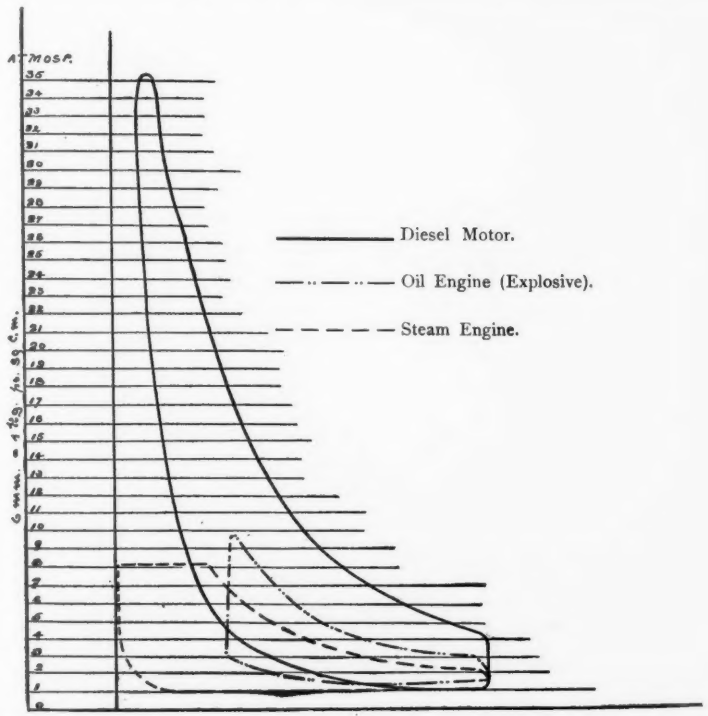


FIG. 3. — COMPARATIVE DIAGRAMS. DIESEL MOTOR, OIL ENGINE, AND STEAM ENGINE.

the other cams into, gear, and thus on the second revolution a full charge of air is drawn in and compressed, and in less than thirty seconds the motor is running at full speed.

Mr. Diesel makes a sharp distinction between the temperature of ignition and the temperature of combustion; the first is a constant value at each pressure, and dependent only on the physical qualities of the fuel, the higher the pressure the lower the temperature of igni-

tion. The temperature of combustion on the other hand is variable, depends on many conditions, and especially on the quality of the air by which the combustion is maintained, but it is always higher than the temperature of ignition.

Diesel's radical departure from all previous practice is in generating a combustion temperature by mechanical compression of pure air, utilizing this temperature to ignite the fuel, and by so introducing the fuel that the heat lost by expansion is practically balanced by the heat added by combustion.

Before the completion of this perfect engine, certain critics of Diesel's theories contended that the dimensions of the cylinder and all other working parts would become so great as to make it impracticable to build such engines. But in Diesel's engines the increase and the decrease in pressures are so gradual that there is no shock. The change from one to the other is always accomplished at a dead point. In all motors relying on explosion for their moving force, and even in the steam engine, there is a direct blow at the moment of ignition or admission. I present here a drawing on which indicator diagrams of a high-pressure steam engine, of an explosion-type motor, and of a Diesel motor have been drawn, based on the same piston displacement. (Figure 3.)

Diesel's and the explosion motor diagrams can be directly compared, since both work on the four-stroke cycle. The steam engine diagram should be quadrupled. This disposes of the objections just referred to.

These second and third diagrams (Figures 4 and 5) are graphic comparisons of the Diesel motor, with a number of the best petroleum motors as to economy in fuel and volume swept by the piston per second. They are given on the authority of Professor Hartmann, well known as a careful and conscientious observer in this field.

The abscissæ represent piston displacement in liters per second, the ordinates petroleum consumption in grams per hour, both figured on the effective or B. H. P. The full lines (Figure 4) embrace the results for full loads, the dotted lines (Figure 5) those for half load. The comparison is between engines which burn ordinary safe lamp petroleum or kerosene; results obtained on benzine or naphtha are not considered, since motors depending on such dangerous fuels can never be generally adopted for industrial purposes. The calorific value of these highly inflammable and explosive liquids is no greater than that of safe kerosene or of fuel oil.

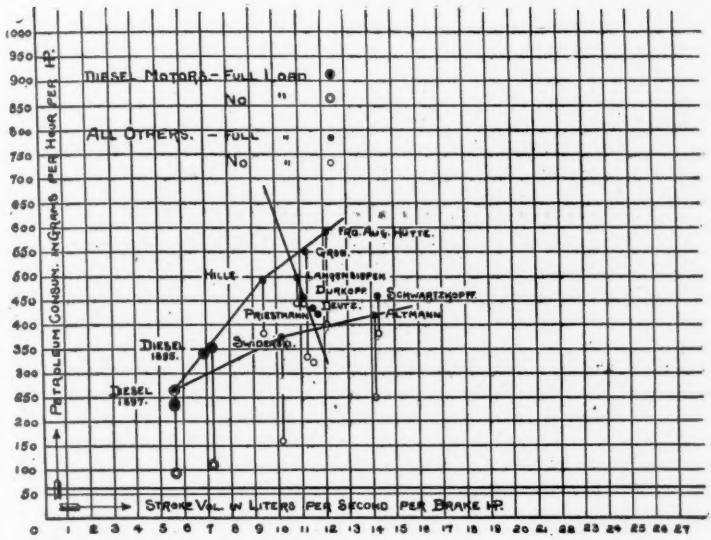


FIG. 4. — COMPARATIVE CHART. FUEL CONSUMPTION AND STROKE VOLUME. FULL LOAD.

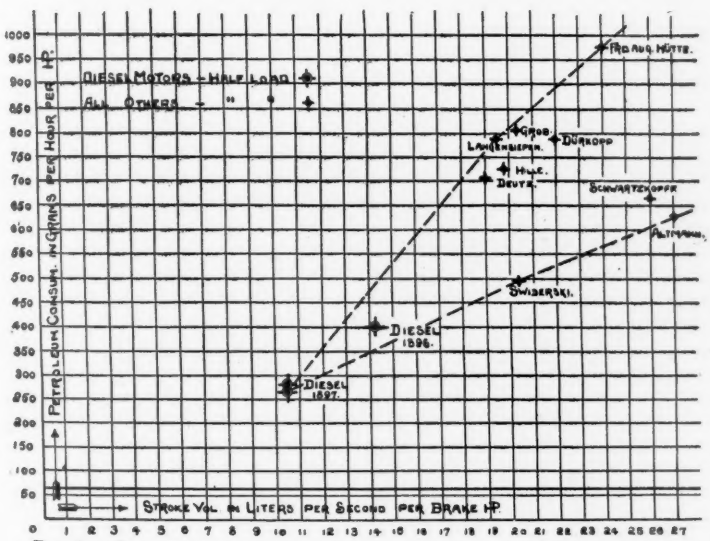


FIG. 5. — COMPARATIVE CHART. FUEL CONSUMPTION AND STROKE VOLUME. HALF LOAD.

You will notice that we find the Diesel results in both cases near the apex of the angle; or, plainly put, both at rated capacity and at half load the Diesel motor shows the smallest cylinder dimensions and the least expenditure of fuel.

Remember that the others represent the best results from engines carefully developed and improved in all mechanical details, while the Diesel motor is but the third one ever built, and that in its construction the practical realization of the theoretical cycle was the primal consideration, mechanical improvement being left for the future commercial exploitation of the machine.

Broadly speaking, the absolute efficiencies of the best known heat engines of to-day range about as follows, taking into account actual calorific values of the fuel and effective or brake horse power:

	Per cent.
Small auxiliary steam engines, pumps, etc.	$\frac{6}{10}$ to 1
Plain slide valve engines in good condition	3 to 5
Single cylinder Corliss engines	6
Compound condensing engines	8
Reheating compound or triple expansion steam engines	12
Best oil engines (explosion type)	16
Best gas engines (explosion type)	19
Diesel motor	28 to 30

All these are compared when running steadily at full load or rating, at point of best economy. But in a large majority of the applications of all these prime movers, the exigencies of the service require them to be run frequently at three-quarters and half load for a large part of their daily service.

It is conceded that in most engines the internal frictions or mechanical losses are a fixed amount, so that a loss of 15 per cent. at full load becomes 30 per cent. at half load. And thermal losses increase even more rapidly, for instance, in steam engines by cylinder condensation. In gas and oil engines the absolute efficiencies have in some cases shown a measured loss of nearly 60 per cent. In the Diesel motor the thermal efficiency is shown to increase with decreasing loads, thus counteracting in a marked degree the loss in mechanical efficiency which it shares with the other machines. From a number of carefully checked tests I found the average drop in absolute efficiency from full to half load to be only 15 to 16 per cent. in the Diesel motor.

FIG. 1. — RUDOLPH DIESEL.

So promptly and easily does it respond to a change of load that a sudden addition of 80 per cent. to the electrical load on the Diesel motor at the Electrical Exposition at New York, by the throw of a switch, was not noticed by observers of the engine or the lights, though promptly registered by the ammeter. For variable load, then, the Diesel motor will show in practice a much greater superiority over all rivals than that apparent from the tabular figures just given.

Up to the beginning of 1898 the Diesel engine had been successfully run only on refined petroleum or kerosene, and this was the fuel used at the Electrical Exposition. During July and August this same engine was subjected to a series of tests, extending over ten weeks, under the supervision of Professor James E. Denton, of Stevens Institute. He reported as follows:

"Tests were made with ordinary domestic kerosene, and with the various grades of petroleum used as fuel under steam boilers, which covered the operation of the engine for upwards of 250 hours, to observe the behavior of the oil and the condition of the interior of the engine after using each oil. During this time economy tests were made of from 1 to 10 hours' duration, the principal commercial results being:

"1. With ordinary colorless domestic kerosene of 120 degrees Fahr. flash, 150 degrees Fahr. fire test, and 0.784 gravity, at about 187 revolutions per minute, an average of 20.8 brake horse power was developed, with an oil consumption of 0.534 pounds, or 0.082 United States gallon, per hour per brake horse power; 13.05 brake horse power with an oil consumption of 0.586 pounds, or 0.0896 United States gallon per hour per brake horse power; and 8.78 brake horse power with an oil consumption of 0.72 pounds, or 0.110 United States gallon per hour per brake horse power. This shows an efficiency on brake horse power of 25.8, 23.5, and 19.0 per cent. respectively. The corresponding indicated horse power efficiencies were 37.7, 41.8, and 41.2 per cent. respectively. These results practically confirm the tests made on an engine rated at 19 brake horse power, at Augsburg, Germany, by Professor Schroeter and other experimenters, which for 17.33 English horse power showed an oil consumption of 0.54 pounds, or 0.0819 United States gallon of American kerosene per hour per brake horse power; and for 9.315 English horse power an oil consumption of 0.63 pounds, or 0.0956 United States gallon per hour per brake horse power, the efficiencies being as follows:

	17.33 HP.	9.315 HP.
Thermal efficiency on indicated HP.	34.15%	38.18%
Thermal efficiency on brake HP.	25.81%	22.12%

"The same increase in indicated efficiency, with reduction of load to one-half shown by the German tests, is found in the New York tests. The mechanical efficiency or the per cent. of the indicated power utilized at the brake of the New York motor was not as great as that of the motor tested in Germany — a result which is possibly attributable to the insufficiency of the foundation of the New York motor, which, by permitting excessive vibration, may have caused a waste of power between the cylinder and the brake. The New York motor showed the greater indicated efficiency, however, which is probably due partly to the slight difference of maximum pressure, and partly to the higher temperature of cooling water, reducing the jacket waste. The heat balance for the two cases is as follows:

HEAT BALANCE.

	New York.		Augsburg.	
	21.51	8.78	17.33	9.315
Heat of combustion accounted for by indicated power	37.2%	41.2%	34.7%	38.9%
Removed by jacket	35.4%	37.4%	40.3%	45.1%
Remainder	27.4%	21.4%	25.0%	16.0%
Total heat of combustion	100.0%	100.0%	100.0%	100.0%

"Examination of the interior of the engine during the use of the kerosene showed that there was no deposit on the surfaces other than an infinitesimally thin film of lampblack on the cylinder and piston head, which did not increase with time. The bore of the cylinder was clean and polished.

"2. With Pratt's fuel oil, which is a dark straw-colored, clear petroleum, of 200 degrees Fahr. flash, 268 degrees Fahr. fire test, and 0.852 gravity, considerably used as a steam boiler fuel, at practically the same revolutions, 20.07 brake horse power were developed, with an oil consumption of 0.613 pounds, or 0.0862 United States gallon, per hour per brake horse power; and 12.56 brake horse power with an oil consumption of 0.681 pounds, or 0.0958 United States gallon, per hour per brake horse power. The operation with this oil was attended with the same insignificant lampblack deposit.

"3. With a black, clear, Pennsylvania petroleum, known as 'Eagle' fuel oil, of 249 degrees Fahr. flash, 296 degrees Fahr. fire test, and 0.849 gravity, at practically the same speed, 20.75 brake horse power

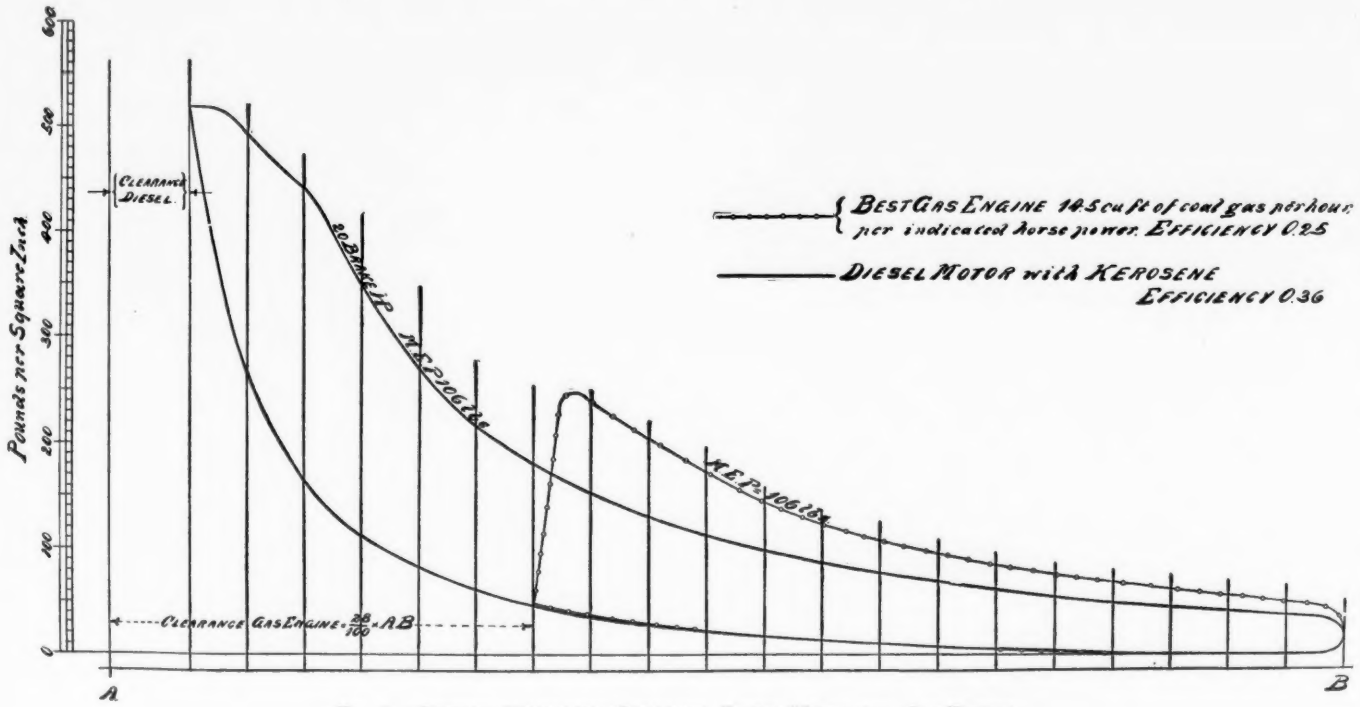


FIG. 6. — DENTON, COMPARISON DIAGRAMS, DIESEL MOTOR AND GAS ENGINE.

were developed, with an oil consumption of 0.56 pound, or 0.0784 United States gallon, per hour per brake horse power. This oil left absolutely no deposit in the cylinder.

"4. With Lima fuel oil, a black, clear petroleum of 0.856 gravity, at about the same speed, 20.73 brake horse power were developed, with an oil consumption of 0.59 pound, or 0.0826 United States gallon, per hour per brake horse power; and 10.77 brake horse power, with an oil consumption of 0.672 pound, or 0.0941 United States gallon, per hour per brake horse power. The operation with this oil was attended with no deposit in the cylinder whatever.

"5. With California crude oil, a black, clear petroleum of 0.846 gravity, with practically the same revolution, 20.07 brake horse power were developed, with an oil consumption of 0.626 pound, or 0.0887 United States gallon, per hour per brake horse power; and 11.44 brake horse power, with an oil consumption of 0.699 pound, or 0.099 United States gallon, per hour per brake horse power. This oil left absolutely no deposit in the cylinder.

"With all these oils the engine started instantaneously and operated very steadily. The action of the valve gear is very smooth and practically noiseless. The combustion occurred with perfect regularity, and was accompanied with no noise other than that due to the pulsation of the floor under the engine. There was also no noise from the exhaust of the engine audible a few feet distant from the chimney into which the exhaust pipe led.

"The exhaust gases with all of the oils carried no soot, a piece of white paper being unsoiled by the impingement of the gases against its surface.

"No deposit was found in a drum forming part of the exhaust pipe, after the entire 250 hours of operation of the motor."

Professor Denton further illustrates the results of his tests by comparing average indicator cards from a gas engine and the Diesel motor. (Figure 6.)

This same engine was afterwards exhibited at the Mechanics Institute Fair, from October 10 to December 3, and during this entire time was run on a low grade of fuel oil, costing about three cents per gallon, f. o. b. tank car, Boston. During this nine weeks' run no fouling whatever was experienced, so that it was possible to run a test the day after the fair closed, without any previous grooming of the engine or any examination of its working parts or valves. This test shows

even more favorable results than those obtained by Professor Denton. The engine has since been moved to Worcester, Massachusetts, where it is in daily operation.

These remarkably favorable results obtained with low-grade fuel oils have, for the present, almost nullified the commercial importance of developing the Diesel engine as a gas motor. But experiments are going on in Germany, both with illuminating gas, power gas, and even blast furnace gases. These will be continued through the year, and the results will be communicated to the American Company.

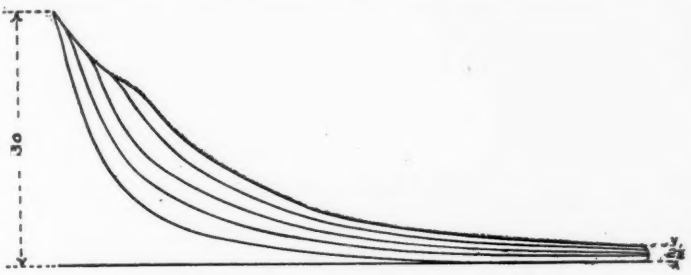


FIG. 7.—INDICATOR DIAGRAMS, DIESEL MOTOR.
Variable Load, Augsburg City Gas.

I take pleasure in presenting an enlarged view of an indicator diagram (Figure 7) taken from the motor while running on Augsburg City gas, merely to show you that the same beautiful and economical cycle is possible with gas as with petroleum.

In the January number of the *Sibley Journal* is found an instructive article by Prof. R. H. Thurston, of Cornell University, concerning the thermal efficiency of steam engines. Professor Thurston refers to the diagram by Capt. H. R. Sankey, Secretary of the British Institution of Civil Engineers, in which he compares the exceptionally economical Leavitt engine of the Louisville (Kentucky) Waterworks, with the performance which would be possible could the Rankine ideal be reached. Rankine first proposed this ideal cycle on January 17, 1854, and Clausius describes the same cycle in 1856, quite independently of Rankine. In short, the Rankine cycle takes in all the usual activities of the steam engine, but takes account only of those losses which are in their very nature inseparable from the cycle. All those vexatious and costly losses which even the best practice does not now, nor ever can, eliminate from the problem, and which may be classed

under the general heads of "radiation" and "friction," are in this ideal cycle considered as non-existent. In Professor Thurston's paper the comparison is made on an equal output in effective work. This I have changed for the purpose of better comparison in this case, by beginning with an equal expenditure in heat units at the beginning of the cycle, thus showing the difference in the output, in place of in the original total expenditure of heat. For the careful elaboration of these diagrams, credit is due to Mr. A. J. Frith, M. E.

In the case of the Diesel engine I start also with the same total expenditure in heat, and trace the flow of this "broad river of heat" through the entire cycle, showing the losses as actually found from a number of tests made on a 20 horse power Diesel motor at New York. While there is every reason to believe that in a larger Diesel engine the losses both from radiation and from friction will show a smaller percentage of the total heat expended, still it would be unfair and unwise to bring into the illustration any merely theoretical deductions. It is better to show the facts as they are, and I content myself simply with pointing out that we are really comparing a 600 horse power steam engine with a 20 horse power Diesel motor. Every fair-minded engineer will concede that for a larger unit the advantage would be greater for the Diesel engine. It is but proper to remark that at the present writing no Diesel engine larger than 150 horse power has yet been built, although units of 300 and 400 horse power are now in process of designing. No special difficulties are apprehended, and the advice of such eminent authorities as Lord Kelvin and Professor Hartmann is in every way favorable to the larger units.

Diagram (Figure 8) shows the reproduction of Captain Sankey's original graphic representation of the actual results obtained during the test of the Leavitt pumping engine at Louisville.

As Professor Thurston says, "This is a very exceptionally good illustration of thermo-dynamic action, and the wastes are very much smaller than are commonly observed in the operation of even good classes of steam engines."

The entire river of heat with a discharge of 183.600 heat units per minute flows from the fire grate. To the right is seen the loss by radiation in the boiler itself. But about three-fourths of the entire flow turns toward the steam pipe. Considerably over one-fifth, however, flows toward the left, toward the economizer, where it loses again by radiation, but is reënforced by a brook coming from the hot well

through the feed pump, and is further joined by a rivulet of returned heat from the jacket water, altogether forming a tributary of no mean size, joining the stream flowing into the steam pipe. Here again, at the bottom, the small rivulet escapes through radiation, but the main body passes on into the engine, where we have the smaller losses by the stream which runs into the jackets, the other which represents the mechanical friction in the engine, and the third, the radiation. By far

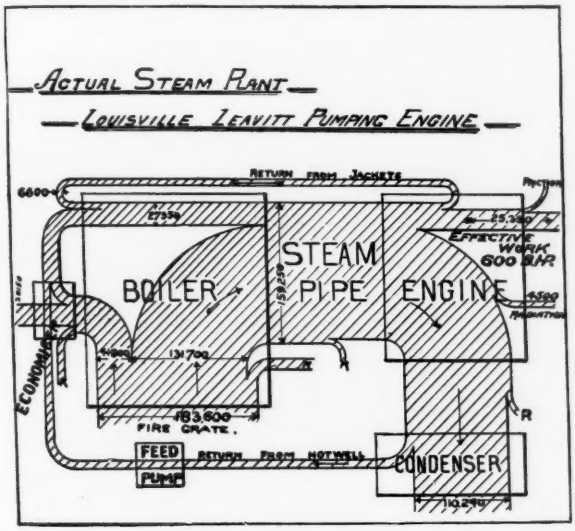


FIG. 8.

the larger stream, however, is lost in the exhaust steam. In passing through the condenser, however, a small brook is diverted toward the feed pump to again do useful work, as above described. We have then (in the upper right-hand corner of the diagram) left but the small fraction of 25,390 heat units, or say in effective work 600 brake horse power, which represents only 13.83 per cent. of the total which is given to the engine; or, as it is customarily expressed, this most excellent engine plant, representing the highest development of modern steam engine practice, has realized an absolute efficiency of only 13.83 per cent.

Diagram (Figure 9) shows the same plant running on Rankine's ideal cycle. In this friction and radiation are swept away by one

happy stroke of the imagination. While a larger stream of heat is diverted to the economizer, this has become so effective that it only allows a very small current to escape toward the chimney. In fact, this represents less than 8 per cent. of the original volume of flow. From the economizer a much larger stream, augmented by the brook flowing from the hot well, re-enters the boiler, so that a total of 178.400 heat units enters the steam pipe, more than a quarter of which does

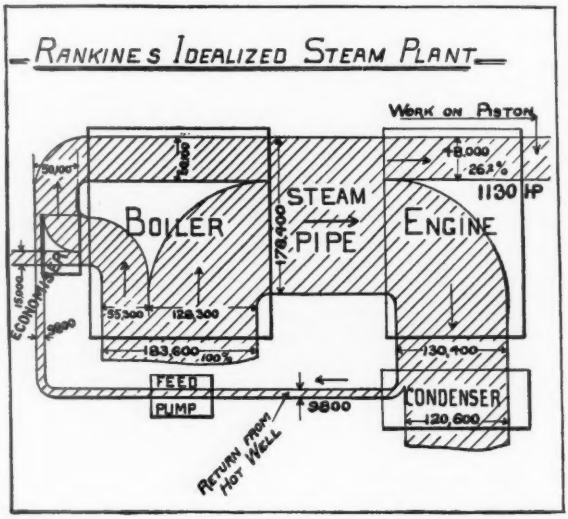


FIG. 9.

useful work on the pistons. But the other three-fourths finds its way as before to the condenser.

In the stream which finally turns our wheels we find 48,000 heat units, giving us 1,130 horse power, or the absolute efficiency of the Rankinized engine is 26.2 per cent. This, then, we may consider as the ideal possibility in steam engine practice, toward which we may strive, but which can never be reached, because we cannot dispose of radiation and friction in actual practice as easily as we have done on paper.

Diagram (Figure 10) shows Captain Sankey's method applied to the Diesel motor, with the same broad river of heat, having a constant flow of 183,600 B. T. U. per minute. The bulk of this enters the

cylinder on its working stroke, but we have before lost more than 30 per cent. from three causes: The one is the actual negative work done in compressing the fresh air of the charge in the main cylinder, and which represents 30,700 B. T. U. A very small stream is the heat expended in compressing air in the air pump, and a third stream, aggregating 22,500 B. T. U., represents the loss by cooling, which flows into the jacket water during the period of compression. The two

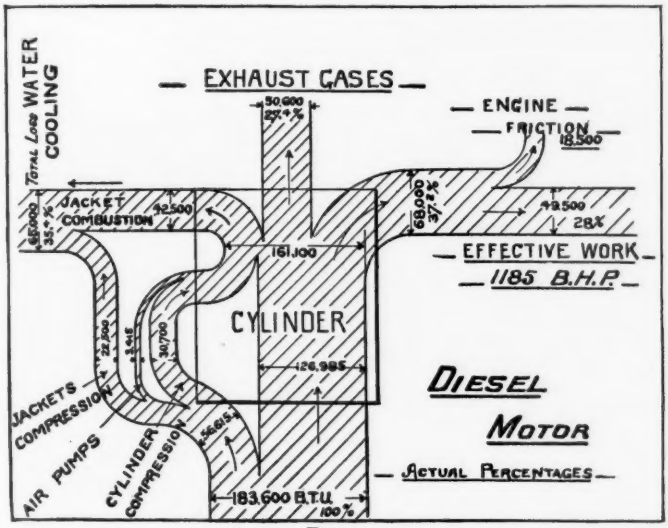


FIG. 10.

losses first mentioned flow back again into the cylinder during the period of combustion in the working stroke, so that we find their total at 161,100 B. T. U. But during combustion we lose again, as shown in the upper left-hand corner, a large stream of heat which flows into the cooling water of the jackets during this period, so that the final and total loss of heat which has flowed into this cooling water amounts to 35.4 per cent. of the total flow. Directly upward is shown a stream of heat amounting to 27.4 per cent. of the original flow, which we lose in the exhaust gases. To the right a good-sized stream representing 37.2 per cent. flows into indicated work. From this, however, we lose a large amount, viz.: 18,500 B. T. U. in engine frictions. Comparing this with the loss shown in the first diagram of the Louisville engine,

the stream looks very large. In explanation, however, we must remember that the steam engine has four effective or motor strokes to one in the Diesel engine. As the latter has to do its whole work in this one stroke, while the frictions retard it in the whole four strokes, it would be entitled to a percentage loss four times as great as that of the steam engine, without being subject to criticism as a mechanically inferior device. Furthermore, the total stream of heat on which this

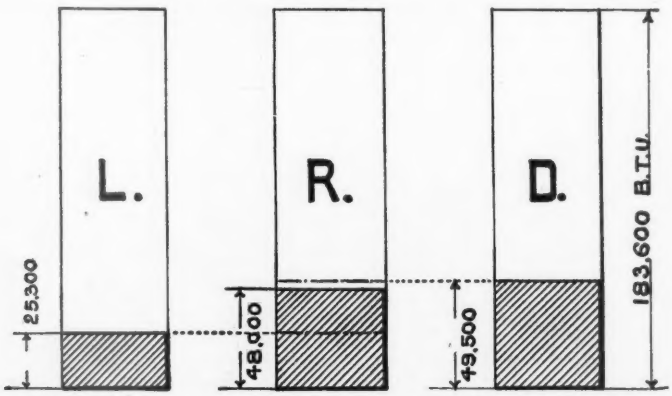


FIG. 11. — COMPARATIVE EFFICIENCIES. LEAVITT, RANKINE, DIESEL.

percentage is to be figured is more than double as large as that which flows into the steam engine. If, then, this outflow in friction should appear eight times as large in actual quantity as that from the steam engine, it could not be considered abnormal.

Finally, we find a broad stream with a flow of 49,500 B. T. U. in the effective work of the engine, a total of 1,185 horse power, or the Diesel motor has shown 28 per cent. absolute efficiency. I must here remark that this 28 per cent. represents a fair average from a large number of tests, while I might have chosen an extreme case which shows over 30 per cent. But I prefer to illustrate in this manner results which we have very frequently obtained, and feel confident of being able to reproduce and even to excel, in all our engines.

Diagram (Figure 11) shows a comparison of the three engines by a representation of areas simply. In each case the large rectangle represents the total of 183,600 B. T. U. with which each engine is charged. The smaller shaded portions of the three rectangles show in

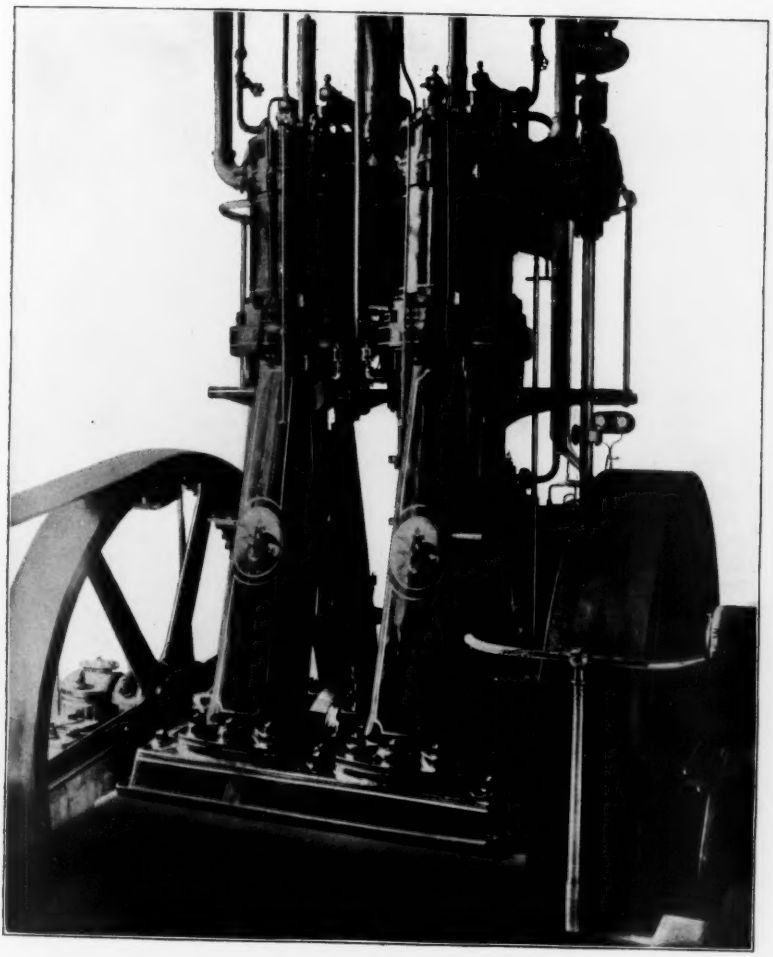


FIG. 12. 60 H. P. TWIN DIESEL ENGINE, GERMAN TYPE.

each case the return made. The rectangles are marked "L" for the Leavitt engine, "R" for the Rankine cycle, and "D" for the actual cycle of the Diesel motor. This shows at a glance that the Diesel motor has in actual practice far outstripped the theoretical possibilities of the steam engine.

Turning again to the diagram (Figure 10), let us examine where further savings can be effected in the Diesel motor. The engine frictions will be no doubt reduced in larger engines, and here is offered a good opportunity for the ingenuity of the designer and the skill of the manufacturer, but after all the field is a rather limited one. The next loss, that through the exhaust gases, can in many cases be very largely reduced by utilizing this heat for heating water or even producing steam for the heating of work rooms, or for various mechanical purposes. The largest loss, that shown toward the left, as the total loss to the cooling water, can also in many cases be utilized for the same purposes, and it is simply a question of temperatures and quantities whether these two streams are to be separately utilized or first combined.

These, however, are questions which can only be discussed here in a general manner, the solution in each case depending on the various local conditions of the problem. If, however, we may assume that in most cases we can utilize one-half of this waste, we would thereby nearly double the absolute cfficiency of the entire plant. In a measure these collateral economies have the same right to be considered as those obtained from the economizer, condenser, and steam jackets in the steam engine; and in this connection the Diesel engine has the comparative advantage that these streams of loss flow at higher temperatures, and can, therefore, in practice be more readily utilized.

Two Diesel engines have thus far been built in America. One is a two-cylinder engine of 60 actual HP., which is driving an Edison generator for 600 lights in the electric plant of the Anheuser-Busch Brewery, in St. Louis, and which they report is giving them an actual HP. at a cost of about one-fifth of a cent per hour in fuel oil.

Careful tests made on the same show the greatest fluctuation in voltage to be $\pm \frac{1}{8}$ volt at full load and $\pm \frac{1}{16}$ volt at half load. This engine has been built entirely according to the German designs (Figure 12). A second engine which presents a wide departure from this is a $2\frac{1}{2}$ HP. marine engine built from our own designs at Newark, New Jersey. This is still in its experimental stage, but it has been run at

speeds varying from 150 to 400 revolutions, and its very simple reversing gear is entirely successful. If the experimental work cut out for it can be completed in time, it will be put on a boat during the summer. (Figure 13.)

A number of stationary engines of 30 HP. are now being constructed. They are entirely self-contained, trunk engines, with two fly-wheels each, and are about 4 feet less in height than the German type. In Europe twenty firms have been licensed to build Diesel motors during the past year, and between 70 and 100 motors are now in actual service.

The engine is, of course, in its infancy, and like all new machines will go through its period of complexity, and finally develop into a very simple and practical form, ready and capable of performing all or nearly all the functions of a steam engine at considerably less cost; and it is my firm belief that before the end of the century the name of Rudolph Diesel will be written on the same scroll with that of James Watt.

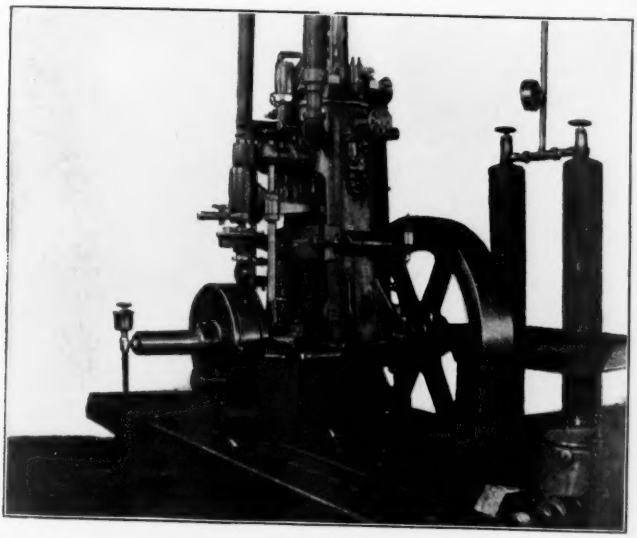


FIG. 13. 2½ H. P. REVERSIBLE DIESEL ENGINE, AMERICAN TYPE.

AN AMERICAN RAILWAY IN COLOMBIA.

By FRANCIS R. HART.

Read March 23, 1899.

ALTHOUGH the Republic of Colombia is the nearest South American neighbor to the United States, the fact that it requires an introduction, both geographical and descriptive, to the majority of North Americans, will make an account of the American interests in that country clearer if prefaced by a brief sketch of its history and physical characteristics. It was Columbus himself who in September, 1502, discovered Cape Gracias á Dios, and in October of the same year touched at what is now Bocas del Toro on the Colombian coast.

Colombia occupies that corner of South America which is connected with Central and North America by the Isthmus of Panamá, the isthmus being politically a part of Colombia. Its coast line on the Caribbean Sea is a little under one thousand miles, and on the Pacific it extends south to its boundary with Ecuador, the southern neighbor of Colombia. On the east and southeast it is bounded by Venezuela and Brazil. In extent it reaches from the equator to about twelve degrees north latitude. In area it is more than double that of the Spanish peninsula, or about 500,000 square miles. The settlement of the country by the Spaniards began in the second decade of the sixteenth century, and by the middle of that century their power was fairly established.

Cartagena, with which this paper will more particularly deal, was founded about 1533 on the beautiful land-locked bay of the same name. In those days of conquest, when the Caribbean Sea was the great hunting ground for freebooters and buccaneers, a safe storehouse for treasure, and a rendezvous for the ships of Spain were a necessity, and led to the construction of strong fortifications to guard the town and harbor of Cartagena, fortifications which stand to-day for the most part as solid and perfect as when first built three centuries ago.

In 1819, Colombia, guided by the powerful hand of the great patriot Bolivar, won her independence from Spain, and established herself as a republic. After many years of internal political dissensions, during

which the country bore successively the names "Republica de Colombia," "Republica de Nueva-Granada," "Estado Unidos de Colombia," a more settled organization was effected in 1885, the independence of separate states abolished, and the country again called the "Republica de Colombia," its present name. To-day Colombia is a single republican State, divided into departments, each department having a governor appointed by the central authority, and an elected legislative assembly.

The lines of communication between the Atlantic, or Caribbean, coast and the interior of the country are by the great river systems, chief among which is that of the Magdalena. The vast importance of the Magdalena River as a commercial highway will be seen at a glance on the map of its valley. This great river is navigable for 750 miles from its mouth by river steamboats of good size. Unfortunately for Colombia, the mouth of the Magdalena is rendered difficult for ocean steamships to enter by reason of the strong currents and shifting bars, and various unsatisfactory attempts to connect the river by an inland waterway with one of the coast harbors or bays made the necessity of a railway connection between the river and one or more coast ports imperative.

In 1880 there was completed and opened to the public service a short railway connecting the town of Barranquilla on the west bank of the river near its mouth, with the open Bay of Savanilla, a few miles west of the mouth. This railway was the property of the Colombian government, but its title passed to an English corporation which extended the railway to a more convenient terminus near the open end of the bay, and constructed a steel pier over 4,000 feet long in order to reach water sufficiently deep to permit steamships to lay alongside. The opening of this railway served to give to Barranquilla a commercial prominence heretofore held by Cartagena and Santa-Marta, both of which coast towns were connected by interior waterways with the river.

The magnificent harbor of Cartagena, rendered doubly secure by the artificial closing of its larger entrance, Boca Grande, by the Spaniards in the early days, had made of that city an ideal port, ranking among the six or seven finest in the world. The water route to the river, consisting partly of a natural delta of the Magdalena, or connecting chain of lagoons, and partly of an artificial canal designed by the eminent engineer Totten, was not sufficiently to be relied upon in

View of Cartagena, from San Felipe.

Street Scene, Cartagena.

all seasons of the year to permit Cartagena to maintain its commercial supremacy in competition with the Barranquilla rail route to the coast. The unsatisfactory nature of the Bay of Savanilla as a harbor, it being an open roadstead, combined with the natural desire of the Colombian people to reëstablish Cartagena in its once prominent position, induced the government and people to urge the building of a railway to connect Cartagena directly with the river.

In 1890 and 1892, concessions were granted by the government of Colombia to Samuel B. McConnico, Esq., an American, giving him the right to build and operate such a railway, and to build and maintain wharves and warehouses at Cartagena, also giving certain exclusive privileges in connection with the rights for the term of fifty years. These concessions and rights were transferred to an American corporation, and the wharves, warehouses, and railway have been built, and a large fleet of river steamboats, operating in connection with the railway, has been placed upon the Magdalena River.

The object of this address to-night is to describe to you briefly the terminal works, railway and line of steamboats, owned and managed by an American corporation in Colombia. The railway and steamboat service taken together act as public carriers between Cartagena and points 800 miles in the interior, and represent an investment of about five million dollars American gold.

The concessions acquired by the American company include the exclusive privilege for a long term of years to maintain a service of lighters and tugs for the disembarking and embarking of cargoes, and for the construction and operation of wharves and terminal warehouses.

The company began active public business in 1891, handling the entire exports and imports of the port, using for the service two tugboats, one of English and one of American construction, and a fleet of lighters. This service continued until June 1, 1893, when the company's pier was completed, and the short terminal railway connecting the pier with the city proper opened to public service.

The pier is constructed of southern pitch pine, heavily creosoted for protection against the ravages of the teredo (*Teredo navalis*), and is 500 feet long by 120 feet wide, having a depth of water at the outer end of 40 feet, and a minimum depth alongside of from 29 to 30 feet. The material for the construction of this pier, the machinery used, and the skilled workmen employed, were all imported from the Gulf coast

of the United States. Extending nearly the whole length of the pier, and in its centre, is a warehouse 80 feet broad, part of which is used as a custom house, and part as a store for export goods. Upon each side of the pier between the warehouse and the water two lines of tracks are laid, and two lines run through the warehouse itself.

Imported goods are taken directly from the vessels' slings into the custom house and there, after examination and weighing, can be placed directly in the cars within the custom house itself. Export goods are discharged directly from the cars into the vessels' slings, or from the cars into the export section of the warehouse. At the inner end on one side of the pier is a special berth for colliers, with an elevated track and tram line to a conveniently placed depot for coals. Immediately adjoining the pier on the shore end, and connected with it by spur tracks, is the company's yard for the construction of steel river steamboats and lighters.

To this pier come regularly the steamships of the Royal Mail Steam Packet Company, the West-India & Pacific Steamship Company, the Harrison Line, the Compagnie Generale Transatlantique, the Hamburg-American Steam Packet Company, the Compañia Transatlantica de Barcelona, the Atlas Steamship Company, the Compañia Italiana, "La Veloce," and vessels of other but less regular lines.

The deep water of the harbor not extending to the city of Cartagena itself, it was necessary to place the pier at a point 1 kilometer from the city walls, and to connect the two by a railway. This short line of rails is laid for about two-thirds of its length across a mangrove swamp, and is solidly built on a causeway of corduroy topped with partially decomposed coral.

At the town end the line crosses an earth and stone wharf, or levee, placed just outside of the city wall, and connected with the city by two gates or ports, and upon the levee is a substantially built corrugated iron warehouse, local freight shed, offices, etc. To this levee, all, of course, under the control of the company, come to leave and take cargoes, the host of small 30- to 80-ton native-built coasting schooners, and the vessels of the coastal steamship companies. The pier, the short line of railway, the levee and warehouses, and the tugs and lighters make up the plant by means of which what is known as the "Terminal Service" of the company is performed.

It has been a matter of particular gratification to the directors of the company that the pier was so designed, both as to material and

An Inside Corner of the City Walls, Cartagena.

The Pier, Cartagena.

method of construction, that it has shown no marked depreciation, either from the devouring worms, so prevalent in southern waters, or from the severe strains both of still and moving weights which have been constantly upon it.

While the terminal works were under construction, the work upon the main line of railway had been carried forward, and almost simultaneously with the opening of the pier service, the first section of the line, reaching from Cartagena to Turbaco, 24 kilometers ($14\frac{1}{2}$ miles), was formally opened to public service.

In making the preliminary surveys and final location of a railway line through a comparatively unsettled tropical country, no very great difficulties are necessarily encountered, but a multitude of small difficulties are almost certain to make vexatious delays. Notwithstanding the fact that Cartagena has been a place of importance for three and a half centuries, and that one-half the line of the Cartagena-Magdalena Railway follows closely the old highway or *Camino Real* of the *Conquistadores*, the only roads leading to the interior from Cartagena are rough mule trails, almost or quite impassable during the heavy rains. The absence of roads, and the thick, luxuriant, tropical vegetation made both the transportation of materials and supplies slow and laborious, and the use of instruments difficult. The inability of the younger engineers to speak Spanish added to the petty troubles of the engineering parties in the field.

After the preliminary work was finished, however, and the chief residencies established, *trochas* cut, mules and horses bought, and a definite organization adopted, the work of location and construction proceeded much as such work would in the United States, but less rapidly. With the exception of the trestle and bridge construction, and a certain amount of rock cuttings, the work was wholly performed by native laborers under the supervision of Americans or Europeans. The peasantry of Colombia, from whom the men employed were drawn, are the native full-blooded Indians and the various shades of Spanish cross-breeds. These men are, for the most part, well built and muscular, but irregular in their inclination for work, and loth to neglect for many consecutive days either the more congenial and less arduous task of field work in their own small plantain or maize plantations, or the welcome shade of their thatched huts. This natural irregularity is further increased by the great frequency of the days of *fiesta*, or Saints' days, which seriously interfere with all work in the Spanish-

American countries. In spite of generous wages offered, the labor problem was a troublesome one during the whole period of construction, and the number of men on the rolls seldom exceeded 1,200 to 1,600.

The length of the road from the pier at Cartagena to the terminus at Calamar, on the banks of the Magdalena River, is 106 kilometers (65 miles), the gauge 3 feet, and weight of rails 50 pounds to the meter. The cross-ties are placed 2,000 to the kilometer, or about 20 inches apart between centers. The maximum grade (made necessary in crossing over the Turbaco hills) is 2.5 per cent., and the sharpest curve has a radius of 478 feet. The highest elevation reached is 200 meters (656 feet) above the level of the sea, at kilometer 23 near Turbaco, and at Calamar, the river terminus, the elevation is but 8.5 meters (28 feet).[1]

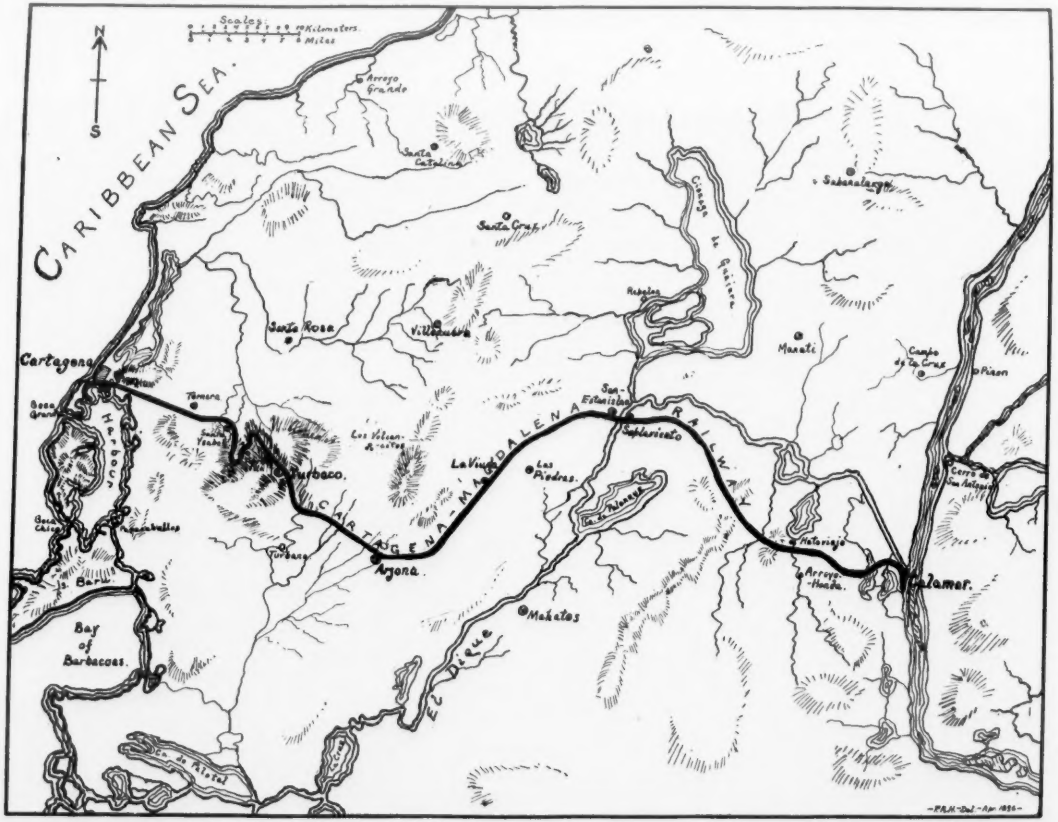
For crossing small streams, ravines, and lowlands subject to overflow, trestles of creosoted pitch pine were built, and the crossing of the Dique (the old waterway connecting Cartagena with the river) was effected by a steel bridge 120 feet long revolving on a central pier. The total amount of trestling was originally 3,358 meters (13,220 feet), but this is being reduced each year by the construction of permanent structures, culverts, etc.

The greater part of the cross-ties used were of fairly durable native woods, but the inability of the local contractors to deliver these sufficiently rapidly, made it necessary to import a certain quantity of American pine and cypress ties. Since the opening of the road, all tie renewals have been made with those of lignum-vitæ, which is so hard a wood that it is necessary to drill holes before the spikes can be driven, and which has a length of life hardly surpassed by the cross-ties of steel often used in tropical countries.

The permanent way is solidly built and well drained (the latter, perhaps, the most important quality of a good railway in the tropics), and withstands the heavy downpours of the rainy season in a manner which from the early experiences of the company's engineers during the construction period had seemed almost impossible.

The first section of the line is ballasted with decomposed or broken coral, and the appearance of the dazzling white roadbed and the lignum-vitæ cross-ties is sufficiently unusual to immediately attract the attention of the traveler from the north.

Along the line of the road are ten stations, with the necessary buildings, and at the termini are large warehouses, car sheds, shops,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Kilometers
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N
S
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Arroyo Grande
Santa Catalina
Santa Cruz
Sabanalarga
Ciénaga de Guaire
Rabolos
Santa Rosa
Villanueva
Cartagena
Manati
Campo de la Cruz
Pitson
Tamera
San Estanislao
Los Vilanos
Turbaco
La Vinya
Los Piedras
Sabanetta
CARTAGENA - MAGDALENA RAILWAY
Cerro de San Antonio
Matarigua
Arroyo Hondo
Palamar
Arjona
Malatos
El Diche
Bay of Barbacoas
P.R.M. Del. Apr. 1926

CHARACTERISTICS OF ROAD.[1]

Name.	From	To		Length in kilometers.	Alignment.			Profile.							Bridges.		
					Length of straight lines in kilometers.	Number of curves.	Aggregate length of curves in kilometers.	Length of level lines in kilometers.	Ascending Grades.			Descending Grades.			Class.	Total lengths in meters.	Water stations.
									Number.	Sum of ascents in meters.	Length of ascents in kilometers.	Number.	Sum of descents in meters.	Lengths of descents in kilometers.			
Main Line	Cartagena.	Calamar.	Main Line.	105.602	77.892	139	27.710	31.146	44	391.96	35.053	37	383.91	39.403	Wooden trestles, Steel bridge.	2884.66 40.00	5
Main Line	Cartagena.	Calamar.	Sidings.	7.398													
Cartagena Terminal .	Cartagena.	Machina.	Main Line.	1.470	.984	3	.485	1.235	2	1.85	.235	—	——	——	Wooden trestles.	473.11	—
Cartagena Terminal .	Cartagena.	Machina.	Sidings.	2.358													

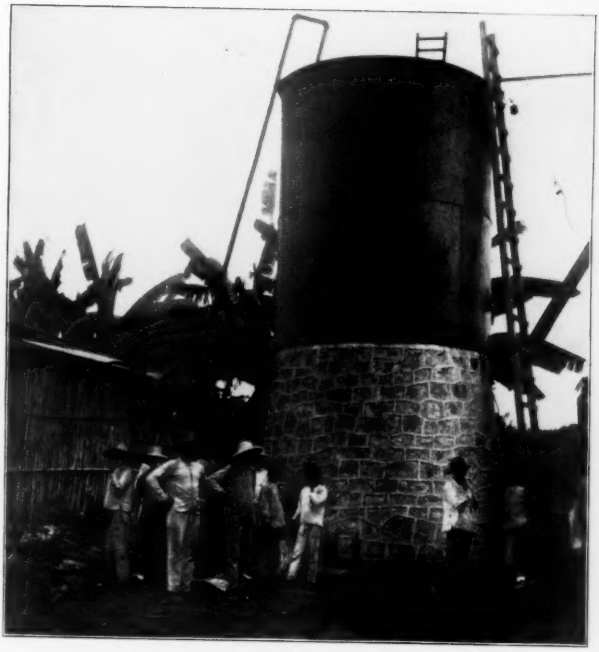
and other necessary buildings built chiefly of corrugated iron. At Cartagena on the broad Plaza de la Independencia is the principal station on the road, and the general offices of the company. This building is constructed of masonry, and is designed to conform architecturally with the principal buildings of Cartagena, and to provide cool and airy offices for the company's officers and employees.

The natural conditions governing the selection of materials and designs for buildings, water stations, etc., in the tropics differ from those influencing similar work in the north. No provision is necessary for snow or frost, but roofs and walls must be able to stand a force of rainfall never seen out of the tropics, and woodwork must be protected against rapid decay during the wet seasons. The white ants are even a more destructive enemy to wood than is the climate, and for this reason sooner or later, woodwork is almost certain to be replaced with masonry unless it is well above the ground. The picture showing one of the water tanks illustrates the most durable type of construction.

The equipment of the road is of the American type, and consists of four 40-ton Rhode Island 8-driver locomotives, three 20-ton Porter and one 25-ton Brooks 4-driver locomotives, and one 12-ton Porter switching engine. The passenger cars are of three types; first, second, and third classes, and the freight and cattle cars of the usual American form. It is, of course, particularly necessary for a railway so far from a base of general railway supplies to be more than usually self-contained in the way of stores and shop machinery, a fact which adds materially to the first cost and the expense of operation of isolated South American railways.

The road was opened to public service for its full length on the 1st of August, 1894, the formal opening having taken place with appropriate and impressive ceremonies on the 20th of July before, the anniversary of the independence of Colombia.

It is difficult to adequately describe the mental attitude of the peasants of the neighboring small towns towards a steam railroad, which in comparatively few months had been stretched across a country that for centuries had known no change. To them the engines were "horses of iron fed with fire," and in their simple language no other words could describe their ideas more accurately. Their curiosity and desire to ride in the strange conveyances were hardly sufficient to overcome the conservatism inbred by generations of unchanging cus-



Water Tank.

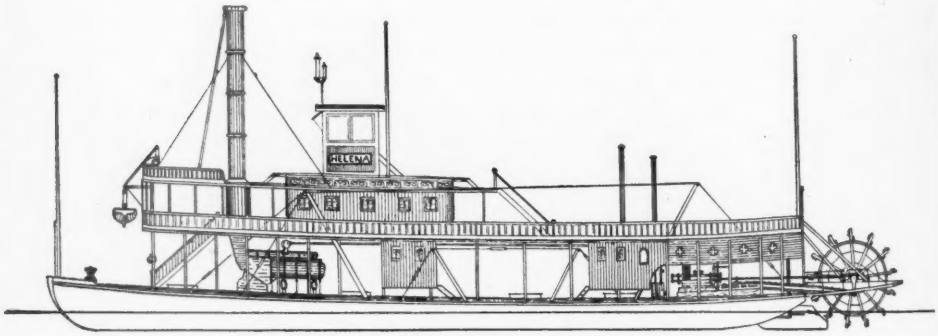
toms, and it has required both abnormally low rates and patient encouragement of small shippers to oust that powerful competitor of the South American railways, the overburdened *burro*, or donkey. Gradually, however, the local business along the line has developed, the cultivation of the neighboring territory increased, the *burro* competition ended, and Cartagena put in a position of dependence upon the railway for its daily supplies.

Except for a multitude of private and public cisterns the city is without any water supply system, and one of the daily tasks of the railway is to bring in water in tank cars. The number of passengers carried per year has averaged 60,000, about 15 per cent. of whom have been first-class passengers. The goods carried locally consist principally of market vegetables and supplies, Indian corn, tobacco, wood, grass, water, cattle, poultry, molasses for the distilleries, and imported manufactured merchandise for the country shopkeepers.

The "through" business, or traffic exchanged between the Magdalena River boats and the railway at Calamar, is of much more importance than the local business, and, owing to the establishment of a service of river boats under the same management as the railway, is rapidly increasing. The goods thus exchanged are the imported products of Europe and the United States purchased by the merchants of the interior towns and the exported products of the interior, consisting of coffee, tobacco, hides, ivory-nuts, cacao, cotton, minerals and specie. Coffee is the most valuable of the exported agricultural products, and tobacco the next. Goods for export are taken on through bills of lading from all the river ports to the pier at Cartagena, and *vice versa*. The movement of imported goods is facilitated by a rule of the custom house permitting the discharge of goods upon the filing of a bond and the payment of a percentage of the duties, the remainder being paid in due course by the consignees in the interior.

The staff of executive officers of the railway are American and English, as are also the chief employees, engine drivers, conductors, terminal superintendents, etc. The office accounting force is partly Colombian and partly foreign; brakemen and stokers are either Colombians or Jamaica negroes. The steamboat captains are either Colombians or foreigners who have resided a long time in the country; the pilots and other officers, and, of course, the crews, are all Colombians. The railway is operated by telegraph, all trains being controlled by the dispatcher at Cartagena, a maximum speed of 30 kilometers per hour

allowed, and an average running speed, including stops, of 26 kilometers per hour maintained. Both roadbed and engines are competent to sustain as high a speed as the average American railway, but the natural conditions have shown higher speeds to be unnecessary and less economical. On the railway imported coals are used exclusively for fuel, but the river steamboats use wood only. The language employed in the actual operation of the trains is English, but all other business of the company is conducted in Spanish, and nearly all of the principal employees speak both languages.



GENERAL DESIGN OF CARGO STEAMBOATS "ALICIA" AND "HELENA" OF THE COMPAÑIA FLUVIAL DE CARTAGENA.

Material: Steel. — Capacity: 300 tons. — Length: 165 feet. — Breadth; 33 feet. — Draught fully loaded: 4 feet. — Speed: 12 miles per hour. Builders: Jas. Rees & Sons Company, Pittsburg.

During the first few years of its operation, the railway suffered from the insufficient capacity of the line of steamboats connecting with the railway at Calamar, and a company was finally organized to undertake that part of the business. The new company, the Compañia Fluvial de Cartagena, put its first boat upon the river a little more than a year ago, and since that time has purchased the fleet of the former contracting company, and added to its own until it has twelve boats in operation. These boats are all built of steel, and have been received in parts from England, Germany or the United States, and constructed at Cartagena. Six of the boats are of 300 tons burthen, or over, and six of them of a lesser size. With the exception of two of the smaller, the boats are all of the stern-paddle-wheel type, a familiar sight on the western and southern rivers of the United States. Those

On the Magdalena River.

Town of Magangué, Magdalena River.

of English, German and American construction are very nearly alike in design, but the engines of the American boats are of the simple high-pressure, non-condensing type, while those on the English and German boats are either compound or triple-expansion condensing engines. No more satisfactory style of boat, both as to general design and machinery, has been found than those built at Pittsburgh, one of which is shown in the accompanying sketch and illustration.[1]

The service performed by the boats can be readily understood from the map of the Magdalena Valley. This service is divided into two parts, the most important being that between Calamar and ports up to and including Dorada, between which ports regular trips are made every few days. At Dorada connection is made with a short railway which transports goods and passengers around the rapids near Honda. These rapids are not navigable in the ordinary sense of the word, although with the assistance of powerful steam winches and cables fastened to the banks, the steamboats necessary for the service above the rapids are more or less easily conveyed thither.

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[1] The approximate specifications of these boats are as follows:

Length, 145′ on deck; beam, 33′; depth of hold, 4′ 6″.

Floor frames, angle steel 2″ x 3″, 18″ apart.

Deck beams of angle steel, 3′ apart, except forward, where for strength they are much nearer.

Plating. Open hearth steel, galvanized. Keel plates, 7 pounds to the square foot. Bow and angle plates and exposed parts, 8 pounds to the square foot. Top plates on sides and bottom, 6 pounds to the square foot. Seams and butts double rivetted.

Bulkheads. One center and two wings, fore and aft, of Nos. 10 and 12 wire gauge steel, stiffened with angle iron uprights, and bulkhead plates rivetted to bottom plating. Compartments made as water-tight as possible.

Cross bulkheads. Five of steel, No. 12 wire gauge.

Keelsons. One longitudinal on each side, of 3″ Z bars.

A breast hook forward stiffens the bow, strengthening the supports for capstan and nigger engine, bitts, etc.

Engine beams. Angle iron and steel plating, well secured.

Transom. Angle iron and steel plating, strongly made for supporting engine beams and rudder.

Decking. ¼″ iron plating, galvanized.

Rudders. Three balance rudders, with stocks and tillers of wood.

Hog-chains. One set on each side of 1½″ steel rods. One set on each side of smaller relief chains. One set of chains and braces suspending wheel support.

Cabin frame, upper deck, etc. Composite wood and iron.

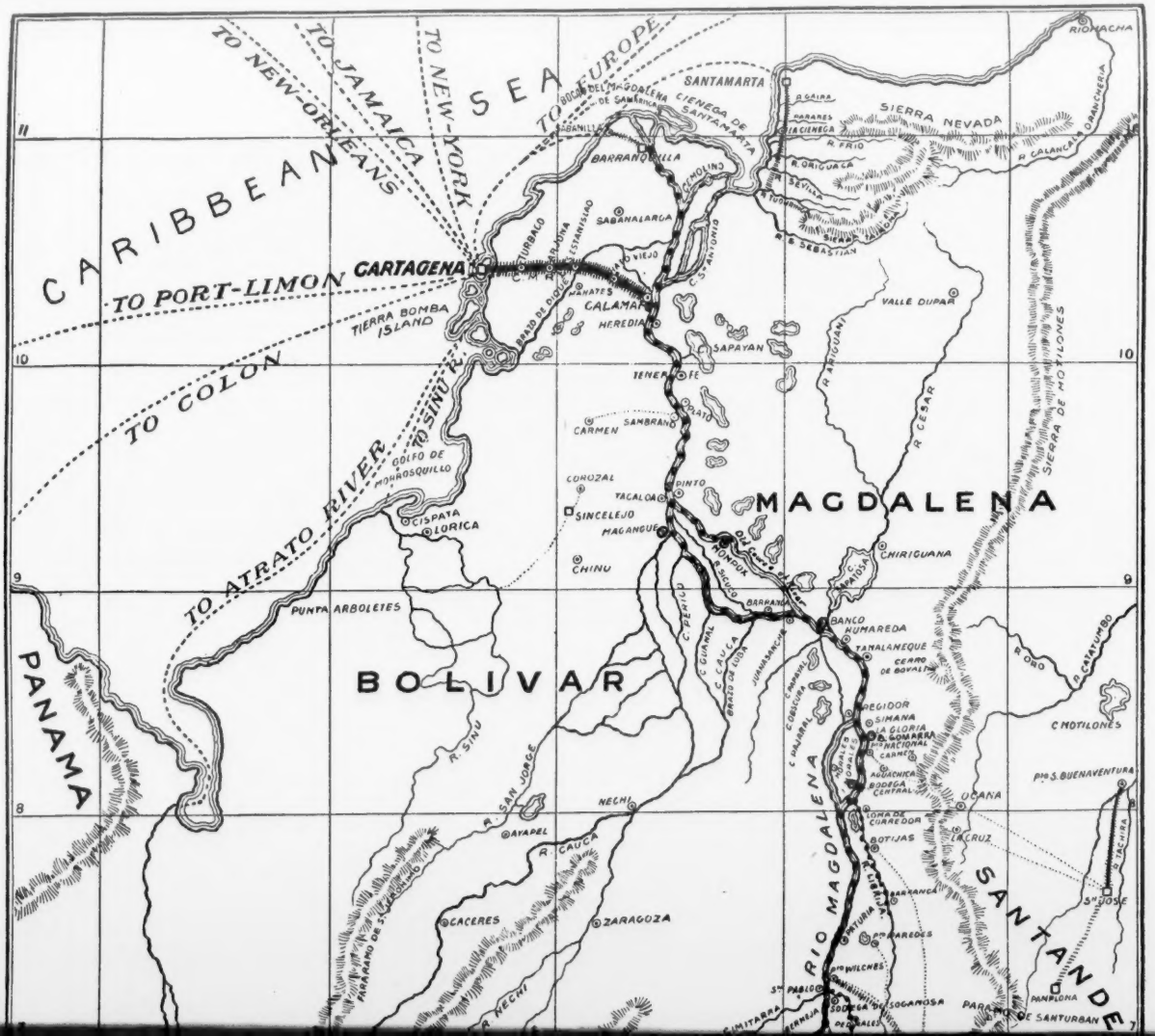
Engines. One pair high-pressure engines, 15″ diameter of cylinders and 6′ stroke.

Boilers. Horizontal, cylindrical tubular type, 3½″ tubes, tested to 225 pounds, and intended for working pressure of 160 pounds. Fire-boxes arranged for wood fuel.

From the terminus of the Ferrocarril de la Dorada, just above Honda, a steamboat service is maintained with ports up to 150 miles further up the river, or about 750 miles from the river's mouth.

Upon the Lebrija and Sogomoso rivers, tributaries to the Magdalena, the steamboat company operates a supplementary service of small steamboats in connection with their main line of boats. About 40 per cent. of the total goods handled upon the river passes through Honda, either by being exchanged between the lower and upper river boats, or by being brought or taken away by the trains of mules constantly on the road between the capital, Bogotá, and Honda. The quick dispatch and safety of goods carried by the boats and railway is in sharp contrast with the transportation of the same goods in the interior. It is not an uncommon sight to see thousands of bales of goods lying on the banks, unprotected from the drenching rains, and awaiting nothing better than a rough trip on the back of a mule for many days, or a moist voyage up some small stream in a leaky canoe.

Nearly all of the river boats are fitted with adequate passenger accommodations, and the voyage from Calamar to the head of navigation and return can be made not only with comfort and pleasure, but is full of interest and novelty. In time it may be appreciated by the American people that within a comparatively few hundred miles from their own coast, and easily reached by comfortable steamships from New York, is a country awaiting and inviting their exploration. Perhaps the newly awakened interest in things West-Indian and Spanish-American may turn our winter pleasure-seekers southward, and make of the Magdalena another Nile. Cartagena, with its ancient walls and fortresses, its palace of the Inquisition and underground passages, and its historical associations with the days of conquest and piracy, can well claim equality with many an old world tourists' haunt in point of interest. In appearance little has changed in the town since those early days, but commerce has taken the place of plunder in sustaining the city, and its water front and warehouses are resonant with the hum of trade where once was the rattle of musketry and the grinding of steel.


CARIBBEAN SEA
TO NEW-ORLEANS
TO JAMAICA
TO NEW-YORK
TO EUROPE
TO PORT-LIMON
CARTAGENA
TO COLON
TO ATRATO RIVER
TO SINU R.
TIERRA BOMBA ISLAND
GOLFO DE MORROSQUILLO
PUNTA ARBOLETES
PANAMA
BOLIVAR
MAGDALENA
SANTANDER
RIO MAGDALENA
SIERRA NEVADA
SIERRA DE MOTILONES
SANTAMARTA
RIOHACHA
BARRANQUILLA
SABANALARGA
CALAMAR
HEREDIA
SAPAYAN
VALLE DUPAR
TENERIFE
CARMEN SAMBRANO
CONOZAL
SINCELEJO
MAGANGUE
CHINU
CHIRIGUANA
BANCO
HUMAREDA
TAMALAMEQUE
CERRO DE BOVALI
REGIDOR
SIMANA
LA GLORIA
GOMARRA
AGUACHICA
BODEGA CENTRAL
LOMA DE CURADOR
BOTIJAS
LA CRUZ
OCAÑA
Pto S. BUENAVENTURA
C. MOTILONES
R. CATATUMBO
R. ORO
NECHI
AYAPEL
CACERES
ZARAGOZA
CIENEGA DE SANTAMARTA
R. FRIO
R. ORIGUACA
R. CALANCALA
R. ARIGUANI
R. CESAR
R. SINU
R. SAN JORGE
R. CAUCA
C. CAUCA
C. DIQUE
BOCA DEL MAGDALENA
BOCA DE SAMARIA
CANAL DEL DIQUE
PUERTO COLOMBIA
GALERAZAMBA
TURBACO
CALAMAR
MANATES
C. SAN ANTONIO
C. SOLEDAD
C. GUAIMARAL
BRAZO DE LOBA
HONDA
SECO
BARRANCA
PUERTO WILCHES
SAN PABLO
SOGAMOSA
PAMPLONA
PARAMO DE SANTURBAN
CUCUTA
SAN JOSE
LA CRUZ
BARRANCA
CIMITARRA
TERNERA
11
10
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MAGDALENA
BOLIVAR
PANAMA
TO ATRATO RIVER
MORROSQUILLO
CISPATA
LORICA
PUNTA ARBOLETES
COROZAL
SINCELEJO
TACALOA
DINTO
MAGANGUE
CHINU
CHIRIGUANA
BARRANCA
BANCO
TAMALAMEQUE
CERRO DE BOYAL
R. ORO
R. CHATUMBO
C. MOTILONES
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SIMANA
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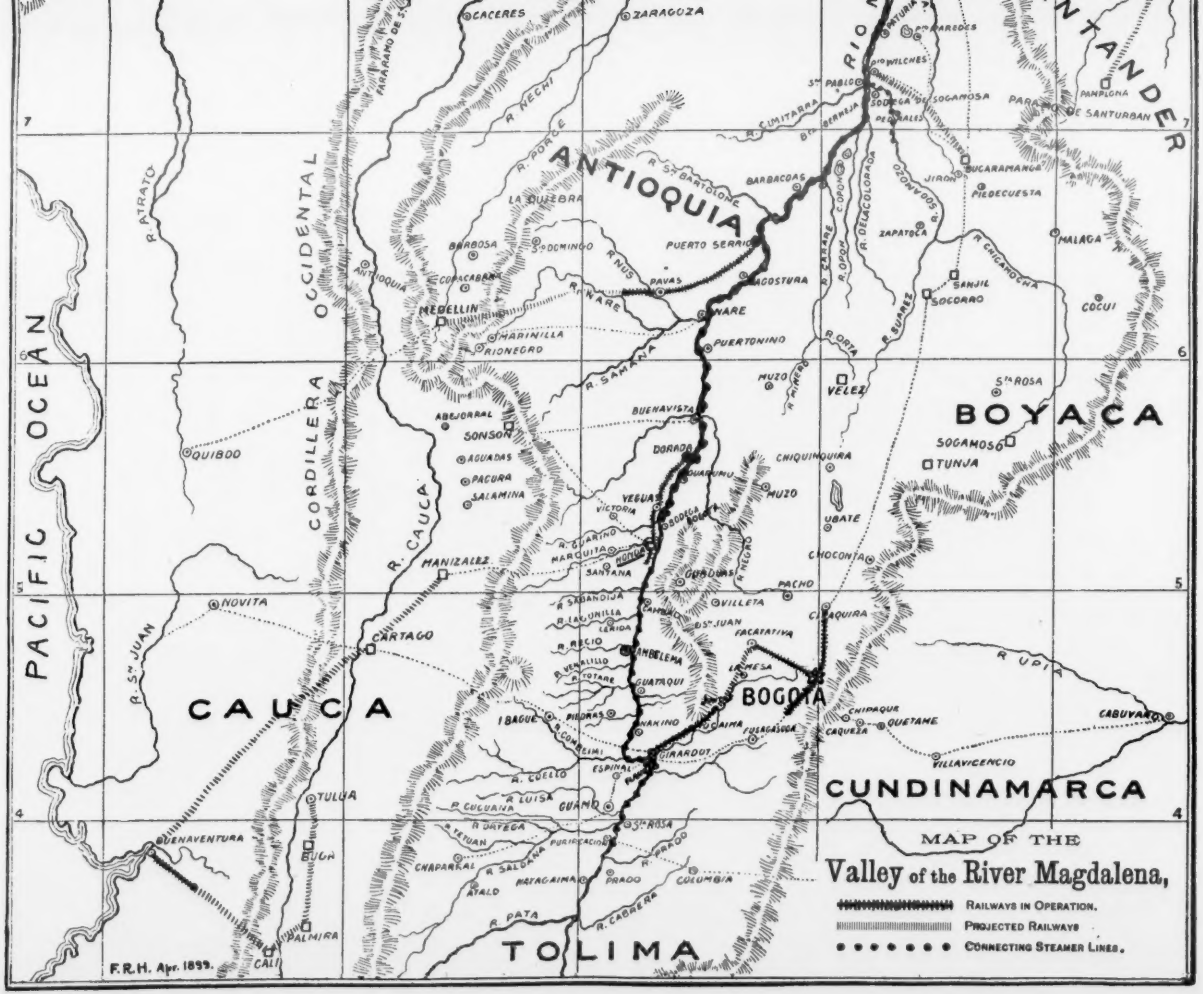


MAP OF THE

Valley of the River Magdalena,

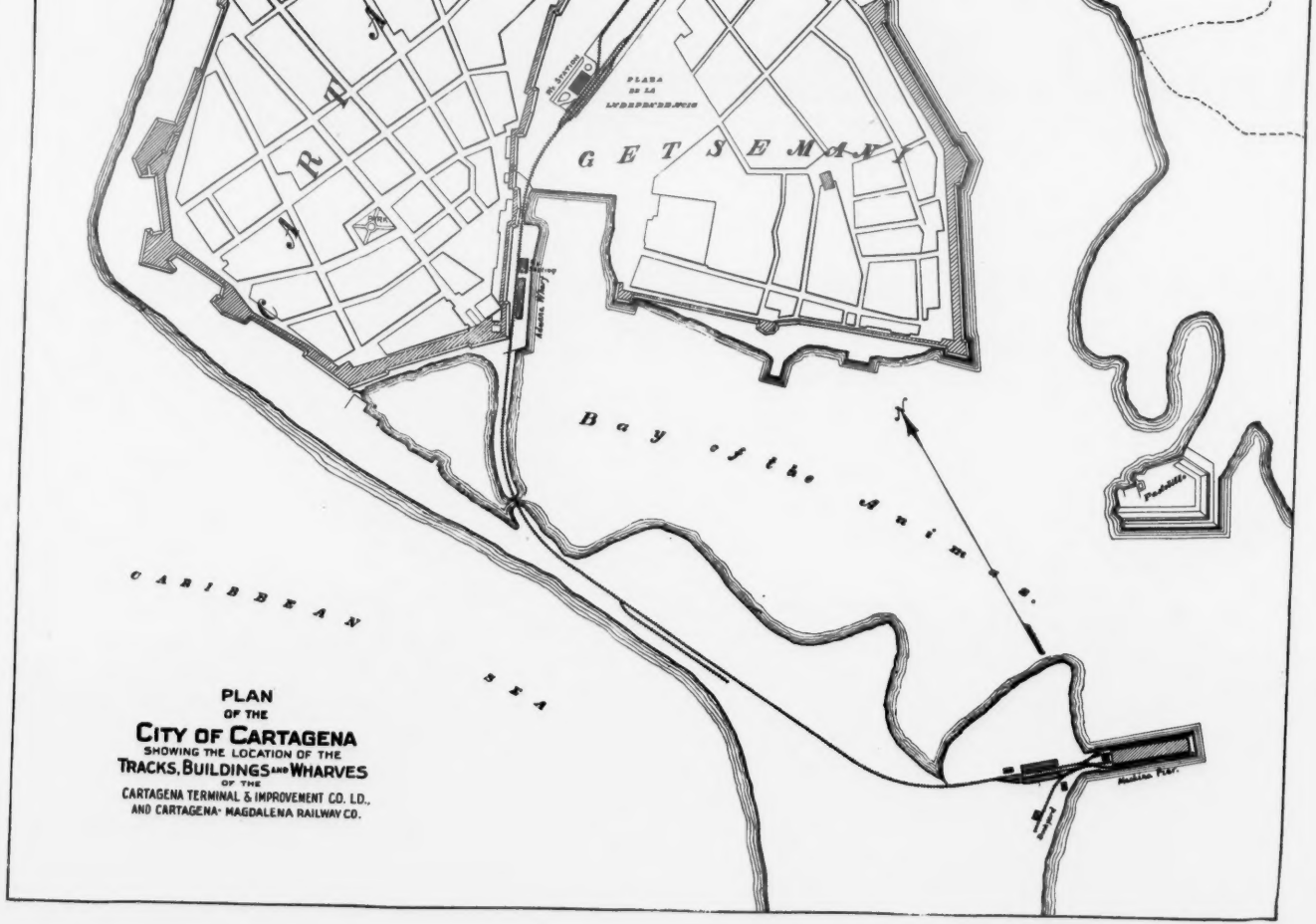
Railways in Operation.

Projected Railways

Connecting Steamer Lines.

GETSEMANI
CHINA
PR

San Tol
Espinal
Genf



PLAN
OF THE
CITY OF CARTAGENA
SHOWING THE LOCATION OF THE
TRACKS, BUILDINGS AND WHARVES
OF THE
CARTAGENA TERMINAL & IMPROVEMENT CO. LD.,
AND CARTAGENA-MAGDALENA RAILWAY CO.

THE GEODETIC OBSERVATORY AT MIDDLESEX FELLS.

By GEORGE L. HOSMER.

Read April 13, 1899.

THE present year marks a radical change in the course of instruction in geodesy at the Institute. The occasion is the completion of a geodetic observatory at Middlesex Fells, where instruction is now given in astronomical observations such as will prepare students for the career of observer in geodetic work. This new feature of the course is the result of the efforts of Professor A. E. Burton to establish a laboratory where geodetic measurements may be made. The introduction of work of this character into the course gives the student an insight into the practical side of geodetic operations, and it creates an interest in the subject and gives a reality to it which class work alone could never do. It will enable the Institute to send out men who have that confidence in their own power which laboratory work of the right kind is able to give.

This observatory is not so general in character as an "astronomical observatory," but confines itself to such observations as have a direct bearing on geodetic work. It corresponds very nearly to the regular astronomical station of the Coast and Geodetic Survey, the chief difference being that it is of a more permanent character. An astronomical station may be defined as a point whose exact position on the earth's surface has been determined (astronomically), and where any data needed in geodetic operations have been obtained. These stations serve two purposes: First, they are of primary importance in the solution of the problems of geodesy, and have, therefore, a use of a purely scientific nature. Second, they have a practical application in geodetic surveying. The character of the observations is in either case the same, namely, the location of the point upon the earth's surface, and finding the direction of some line of the survey. At this observatory all of the observations are of this character, and all are concerned with geodetic operations.

The part which the astronomical station plays in these problems may be better understood if we inquire a little more closely into the nature of the problems themselves. In the first case before mentioned,

the object of geodetic operations is the determination of the size and figure of the earth. By the "figure of the earth" we may mean either the form of the actual surface with all its irregularities, or the form of some simple mathematical surface which is a close approximation to the true figure. For most purposes it is only this fictitious surface which we can use, and the closeness with which this surface approaches the true one must depend largely upon the application we intend to make of it. For nearly all purposes the oblate spheroid is the adopted figure. The true figure of the earth is found by determining the local deviations of the surface from this imaginary spheroid. The problem of finding the earth's form is, therefore, divided into two distinct parts, the determination of the simple mathematical surface best representing the true figure, and the study of the true figure by comparison with this fictitious surface.

For the purpose of obtaining the elements of the spheroid it is necessary to combine measurements of arcs of a meridian with measurements of the latitudes of the extremities of these arcs. In other words, we must compare the lengths of arcs on the surface with the angles they subtend in order to know the form of the meridian ellipse. The work of measuring the length of an arc belongs to the field work of geodesy, and is not directly concerned with the astronomical observations. The second part of the arc measurement requires that astronomical stations should be established at the north and south extremities of the arc. Here we must determine with extreme accuracy the latitudes and longitudes of these points. This determination of the position is the most important set of measurements made at the point, but the station also serves other purposes, as will be seen later on. The measurement of a number of such arcs (theoretically two) will determine the form and size of a spheroid which will be a general average of all parts of the surface covered by the measurements.

Having obtained the representative figure, our next step is to find where and how much it differs from the earth's true figure. The astronomical station affords a means of making these measurements. First, it must be observed that our determination of the astronomical position depends directly upon the direction of gravity, since it is only by means of a spirit-level or a plumb-line that we can determine that important point of reference, the zenith. Second, any change in the direction of the surface produces a change in the direction of gravity. If this change is not in accordance with the change in a spheroidal

surface, there will be a "local deflection of the plumb-line" at that point; the vertical line will be different from what it would on the spheroidal surface. This difference is known as "station error." The magnitude of the "station error" is obtained as follows: Astronomical stations are taken in groups and connected by a triangulation survey. This triangulation enables us to compute the position of one point from another. Now by reducing all of the observed positions to one station and taking the mean of the results, we get a position nearly what it would be if the surface were truly spheroidal. By reversing our computation we may find such a position for each station. These computed positions show the direction of the vertical on a spheroid, while the observed position shows the direction of the vertical on the "geoid." The difference at any station is the "station error" for that point. It is never more than a few seconds. Such comparisons as these taken over all parts of the surface would enable us to find the true figure of the earth.

This problem may also be solved by means of the pendulum, and this is becoming an extremely important method in geodesy. The variations in the force of gravity show the variations in the distance to the center of the earth; hence a measurement of this quantity at known points will enable us to find the earth's figure. The measurement of the force of gravity by swinging a pendulum requires an accurate knowledge of the rate of the timepiece used in getting the time of an oscillation. Furthermore, the observation is of little value unless its exact position upon the earth's surface be known. Hence it is almost a necessity that the astronomical station and the pendulum station should be at the same point.

So much for the use of the astronomical station in the problem of finding the earth's figure. Having found the size and form, we now come to the application of this knowledge to a practical end. Our problem is to carry on a survey over an area so extensive that it becomes necessary to take into account the curvature of the surface. In its application to geodetic surveying the astronomical station again finds two uses. Any network of triangles used in the survey of a large area must be located upon the spheroid before calculations can be made; *i. e.*, it is necessary to know just what part of the spheroid we are using. Furthermore, astronomical location serves as a check upon the triangulation, for while the latter is far more accurate than the former for short distances, it is not so for long ones. The accu-

racy of astronomical location is nearly the same for all parts of the surface, while the errors of triangulation accumulate with distance.

From the foregoing it will be seen that the immediate problems of the astronomical station are the exact determination of latitude, longitude, time, and azimuth, as well as the force of gravity, and incidentally the magnetic elements. As these measurements are all of the most precise character, it is necessary, in order to secure the desired degree of accuracy, that the work be done under the most favorable conditions, and success will depend largely upon the care and skill exercised in selecting the site of the station, and in the arrangement of the details of the building. It is essential that the ground should be free from vibrations such as would be caused by railway trains or heavy teams. The surrounding air must be free from the smoke and light of the city; if magnetic work is to be done, anything tending to cause magnetic disturbances must be avoided; and since the point is to be connected with the surrounding triangulation, it ought to be visible from well established triangulation stations. For this reason it is usually on elevated ground. The building need not be a large one, but sufficient to enable the observer to work conveniently about his instruments, and to afford the proper shelter. The instrument must be mounted upon a firm support, usually a stone or brick pier, which must be entirely separated from the floor of the building, as the slightest jar is sure to be communicated to the instrument. The spot ought to be selected with regard to its permanence, for the location is of value and might be of great service in any future work of a similar character. From these considerations it would seem that a public reservation, where there is little danger of the points being disturbed, and where railroads and heavy teams are likely to be kept at a considerable distance, would offer a good location. If, in addition, the point can be selected so as to be visible from important triangulation points, and is free from magnetic disturbances, it fulfills all of the requirements of a good station.

When it was proposed that an observatory should be built by the Civil Engineering Department of the Institute, a careful study was made of the public parks near Boston to find a spot which fulfilled as many as possible of the above named conditions. The spot that was selected is unusually well suited to the purpose, for it not only satisfies the necessary conditions, but has the additional advantage of being comparatively near the other buildings of the school. The site of the

FIG. 1. — THE GEODETIC OBSERVATORY.

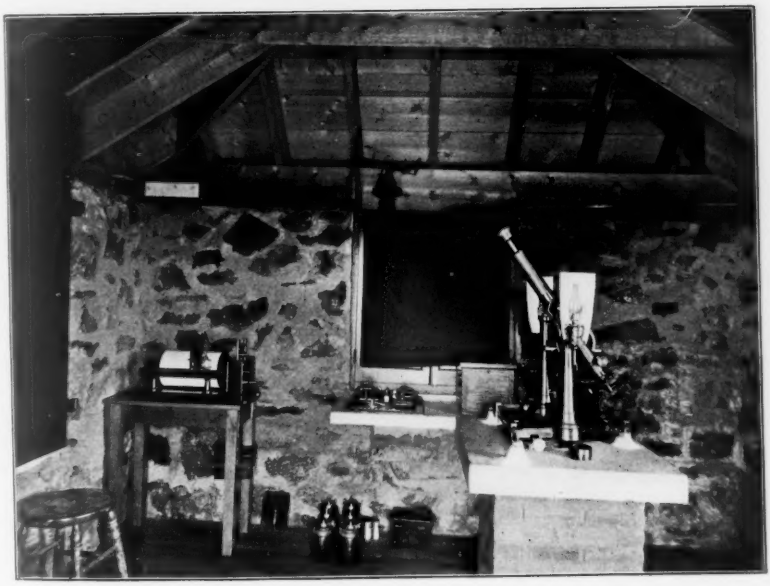


FIG. 2. — THE INTERIOR OF THE OBSERVATORY WITH THE INSTRUMENTS IN POSITION.

observatory is in the southeastern portion of Middlesex Fells, about one mile from the city of Malden. The nearest point on the railroad is at a distance of two-thirds of a mile, and the nearest highway is over a quarter of a mile away. The nearest park road (where only light travel is allowed) is 460 feet distant. There is little danger under these circumstances that much trouble will be caused by vibrations. The atmosphere is very clear, on account of the elevation of the point and its distance from all settled districts; this is a condition which could not be reached near a city. In regard to magnetic disturbances the spot is well chosen. The nearest electric current is one-quarter of a mile away, and moving masses of iron such as carriages and bicycles cannot approach nearer than about 460 feet. This is a condition not easy to obtain in combination with so many other advantages. The number of triangulation points visible is quite large, including Blue Hill, Prospect Hill, State House, Nahant, Powderhorn, Tufts College, and Bear Hill. These are all important points in the Massachusetts system of triangulation, and make it easy to determine the position of the observatory very accurately. The building itself is about 15 feet square, and is built of the field stone found in the vicinity. It is set upon an outcropping ledge whose elevation is about 290 feet above mean tide. There is a clear horizon in nearly all directions. In the roof of the building is a slit about 14 inches wide extending in the north and south direction. The pier on which the instrument is mounted is placed directly underneath this opening. It is set directly upon the ledge, and built up to a height of about 3 feet above the floor. It is made of brick, and is capped with a stone about $2\frac{1}{2}$ feet square and 4 inches thick. The instrument is mounted so as to swing in the plane of the meridian. The opening in the roof is extended down the walls to about the level of the top of the pier, so that any portion of the meridian (above the horizon) may be seen. By placing the pier a little out of the central position, it was found possible to see Blue Hill and Prospect, through the windows from the pier, thus avoiding an eccentric station in locating the point by triangulation.

The instrumental outfit consists of a $2\frac{1}{2}$-inch portable transit instrument provided with a micrometer and a level for latitude observations, a chronometer and a chronograph. With these instruments latitude, time, and longitude observations may be made. Beside these there is a complete magnetic outfit (*i. e.*, a magnetometer and a dip circle), and an alt-azimuth instrument with circles reading to seconds by

means of microscopes. A pendulum apparatus is now being made for this observatory. These instruments, together with several smaller ones, make up an outfit with which all of the observations necessary in geodetic work can be made. With this equipment the students of geodesy have been carrying on a regular series of observations for latitude, time, and longitude. The latitude observations have been made both with the zenith telescope and the vertical circle. The two sets of results show a close agreement. In the longitude work the method of moon culminations has been used chiefly. A little later this observatory will have a wire from one of the telegraph offices, so that it may be connected with other observatories, and its longitude very accurately found by the "telegraphic method."

A brief description of the method of making and recording these observations may not be out of place here. The transit instrument, with which the time observations are made, is mounted so as to revolve in the plane of the meridian. In the "field" of the telescope are five vertical threads (spider threads stretched across a metal ring). These are spaced so that a star at the equator travels from one thread to the next in about twelve seconds. The observation consists in noting the time that the star crosses each thread and recording it. After the proper instrumental corrections are applied to these times the result is a measurement of the local sidereal time at the instant of the observations, and shows the error of the chronometer. The method of recording is that known as the "American method," *i. e.*, by chronograph. The essential parts of the instrument are a revolving cylinder carrying a sheet of paper, and a pen, in contact with the paper, moving along an element of the cylinder. The two motions cause a spiral line to be traced on the sheet. The pen is attached to the armature of an electro-magnet, the coils of which are connected with a chronometer, a key, and a battery. This chronometer is arranged to break the circuit at regular intervals (two seconds), thus causing the pen to move sidewise and make a notch on the sheet. In this way the sheet is graduated into minutes and seconds of the chronometer time. When the observer wishes to record the instant that a star crosses a thread, he presses the key, and makes a notch on the paper between two of those made by the chronometer. The position of this notch is easily measured, and the corresponding time known within about a hundredth of a second. If the transit of the moon be included in the set of observations on stars, its position at the instant can be found; a com-

parison with the (known) Greenwich time when it had the same position gives the longitude of the place of observation. But a far more accurate way of finding longitude is by telegraph. The main line is so connected that records can be made at the same instant on chronographs at each end of the line. In this way the local times of the two places are directly compared so that the difference of longitude becomes known. Observations for latitude are most accurately made by the zenith telescope. The accuracy of the method depends upon the fact that the measurements are all differential. Such measurements are more easily and more accurately made than absolute values. Stars are selected in pairs, one north and one south of the zenith, and at nearly equal distance from it. A micrometer serves to measure the small difference of the zenith distances, while a spirit level shows the amount the telescope has moved between the two measurements. From these measures the latitude is easily deduced. The latitude of the observatory has also been found by measuring altitudes of the pole star, by means of an alt-azimuth instrument and a basis of mercury. These two independent determinations check each other very closely. These descriptions merely serve to show what kind of observations are being made and do not go into details. All of these methods are very fully explained in various reports and text-books. Examples of time and latitude observations are given at the end of this paper.

A considerable amount of work has been done here this year which has never before been possible at any of the Institute buildings, such, for example, as tests of delicate spirit levels, tests of pivots, etc. This is also quite true of the magnetic work. None of the observations previously made could be regarded as really valuable; all that was attempted was to teach the methods. At this place there is practically no local disturbance, and the observations ought to be trustworthy. In all of this work it is the aim to get reliable results, so that the student is actually observing, and not merely going through the manipulation in order to learn it. The work offers a large variety of problems, and the student is continually working at something new. He is thrown upon his own resources and held responsible for his results, just as he will be in his later experience. In this way he is trained to attack new problems, and is kept constantly on the watch for causes tending to affect the accuracy of his results.

The work that has been done this year is only a beginning, but it is a beginning under favorable conditions. When the latitude and

longitude have been accurately determined and the position connected with the neighboring survey points, this observatory will become an important station in the Massachusetts system of triangulation. The location is an excellent one, and has everything in its favor for accurate work, so that the outlook for the future is very encouraging.

Following are the records of two sets of observations made at the observatory, given in order to show the kind of observations and the method of working them up. These are very nearly the same as those of the Coast Survey and other similar surveys, so that no special explanation will be necessary.

TABLE I. TRANSIT RECORD.

Station, Middlesex Fells. Date, November 15, 1898. Chronometer, Bond 541.

π Pegasi.	γ Lacertæ.	10 Lacertæ.	ι Cephei.	π Cephei.	Br. 3077	τ Pegasi.	ι Androm.
Clamp E.	E.	E.	E.	W.	W.	W.	W.
32.0 56.0 62.5 26.0 94.5 82.0 82.0 12.5	12.5 15.0 27.5 13.75 × .0092 −.02 = +0.11	48.5 39.0 46.0 40.5 94.5 79.5 79.5 15.0	Temp. = 45° F.	59.0 30.0 41.0 48.0 100.0 78.0 78.0 22.0	22.0 9.0 31.0 15.5 × .0092 +.02 = +.16	32.0 56.0 61.0 28.0 93.0 84.0 84.0 9.0	Temp. 43° F.
	b_e = +0.11				b_w = +.16		
22 03 42.10	25 10.71	32 53.50	43 45.90	23 01 46.64	06 21.74	13 53.08	31 19.15
56.79	29.95	33 09.41	44 15.82	02 34.00	43.82	14 06.64	35.84
71.45	48.85	25.12	——	03 21.63	07 06.40	20.15	52.30
86.10	08.42	——	45 15.85	04 08.95	28.67	33.70	69.52
100.96	27.25	57.05	45.82	04 56.00	51.40	47.10	86.42
22 03 71.48	25 49.04	33 25.23	44 45.87	23 03 21.44	07 06.41	14 20.13	31 52.65
−.02	−.02	−.02	−.04	−.06	−.03	−.02	−.02
+.13	+.17	+.14	+.25	+.52	+.28	+.16	+.22
−.03	−.01	−.01	.00	+.01	+.01	+.01	+.02
04 11.56	25 49.18	33 25.34	44 46.08	03 21.91	07 06.67	14 20.28	31 52.87
05 30.65	27 08.45	34 44.50	46 05.99	04 42.76	08 26 16	15 39.26	33 12.14
1 19.09	1 19.27	1 19.16	1 19.91	1 20.85	1 19.49	1 18.98	1 19.27

NOTE. — Value 1 div. level = 0."55. Hourly rate = +.033. Pivot inequality +.02. A dash indicates that the thread was missed.

TABLE II. REDUCTION OF TIME OBSERVATIONS.

	STAR.	Pos.	$a-t$.	C.	A.	Cc.	Aa.	ΔT $a-t-Cc-Aa$.	v.	
			m. s.							
	π Pegasi	E	$+t$ 19.09	-1.19	$+.20$	$-.02$	$-.15$	19.26	.04	
	7 Lacertæ	E	19.27	-1.55	$-.20$	$-.02$	$+.15$	19.14	.08	
	10 Lacertæ	E	19.16	-1.28	$+.09$	$-.02$	$-.07$	19.25	.03	
	ι Cephei	E	19.91	-2.43	$-.96$	$-.03$	$+.72$	19.22	.00	m. s. $\Delta T = +1$ 19.21.
	π Cephei	W	20.85	3.82	-2.05	$+.05$	$+.160$	19.20	.00	h. m. at 22 52.
	Br 3077	W	19.49	1.81	$-.44$	$+.03$	$+.34$	19.12	.08	
	τ Pegasi	W	18.98	1.09	$+.36$	$+.02$	$-.28$	19.24	.04	
	ι Androm	W	19.27	1.36	$-.01$	$+.02$	$+.01$	19.24	.04	
			$a-t$.	C.	A.	Cc.	$a-t-Cc$.	Aa.	$a-t-Cc-Aa$.	$c=+.029$
1st approx.	Mean of time stars	E	19.17	-1.34	$+.03$	$-.04$	19.21	$-.02$	19.23	$a_e=-.78$
	Az. star	E	19.91	-2.43	$-.96$	$-.07$	19.98	$+.75$	19.23	$a_w=-.76$
	Mean of time stars	W	19.25	1.42	$-.03$	$+.04$	19.21	$+.02$	19.19	
	Az. star	W	20.85	3.82	-2.05	$+.11$	20.74	$+1.56$	19.18	
2d approx.						$-.02$	19.19	$-.02$	19.21	$c=+.014$
						$-.03$	19.94	$+.73$	19.21	
						$+.02$	19.23	$+.02$	19.21	$a_e=-.755$
						$+.05$	20.80	$+1.60$	19.20	$a_w=-.778$

TABLE III. LATITUDE RECORD.

Middlesex Fells. December 7, 1898. Temple transit.

STAR.	Mag.	Z. D.	N. or S.	Chr. time.	Microm.	LEVEL. N.	LEVEL. S.	REMARKS.
		° ′		h. m.				
τ Pegasi . .	4.6	19 16	S.	23 13	18.075	17.2	90.8	Temp. 37° F. Lev. "O" toward eye piece. E. P. for microm.
4 Cassiop .	5.8	19 16	N.	18	17.027	85.5	11.3	

$\frac{1}{2}(\delta_s + \delta_n$	42°	27′	47″.00	t 1.048	90.8
					17.2
$\frac{1}{2}(Z_s - Z_n)$		− 1′	21″.64	log 0.02036	108.0
	42°	26′	25″.36	$l.\ r.$ 2.19257	54.0
$\frac{1}{2}(l_n - l_s)$			+ 2.80	2.21293	
	42°	26′	28″.16	163″.28	85.5
					11.3
$\frac{1}{2}(r_s - r_n)$			− 0.03	2′ 43′.28	96.8
φ =	42°	26′	28″.13	1′ 21″.64	48.4

ON RAPID METHODS FOR THE ESTIMATION OF THE WEIGHT OF SUSPENDED MATTERS IN TURBID WATERS.

By CHARLES L. PARMELEE and JOSEPH W. ELLMS.

Probably the most notable characteristic of the surface waters of the central and western portions of the United States is the great variation in the character and amount of the suspended matters which they contain. In the purification of such waters the removal of the suspended matters is a very important factor, not only from an absolute point of view, but also from the influence which they exert upon the various steps in processes of purification. On this account reliable information as to the amount of suspended matters present in the water to be purified is very essential, in order to adjust properly the several steps in the process that the water may be handled in the most efficient and economical manner. This information should be readily and quickly available; in fact, unless it is so, its value is lost, save as a matter of record upon which future judgment may be based.

So far there has been satisfactorily developed no better means of measuring the amount of suspended matters present in water than by determinations of its weight, volumetric measurements not being sufficiently accurate. The determination of the weight of suspended matters in water, dealing as it does with comparatively small amounts of solid material distributed through large volumes of water, involves difficulties which are not apparent in any hasty consideration of the subject. These difficulties are considered in detail in the following section.

Gravimetric Determination.

The gravimetric method consists in weighing the residue left after evaporation of a given volume of the water and also the residue from an equal volume of the same water after being filtered, in order to obtain the weight of the dissolved constituents. The difference between the two weights represents the weight of the suspended matters. This is the only direct means of measuring the weight of

suspended matters. Any other method should be compared with this as a standard, and in the formulation of laws and abstract relations, reliance should be placed on the gravimetric determination as a basis. This method is too time-consuming to fulfill satisfactorily the requirements outlined above, and this paper contains descriptions of certain rapid methods for the estimation of the weight of suspended matters, which the writers have studied with considerable care, and which are apparently sufficiently applicable under the conditions described to warrant their presentation.

In any scientific study one of the first constants to be determined is that of the base of reference. Absolutely speaking, nearly all standards are somewhat in error, and in the case in hand the standard of reference, the gravimetric determination, is liable to errors of considerable magnitude. These are as follows:

1. Imperfect drying of the residue after evaporation of the water. Under the best conditions this error is very low in amount, and it should never exceed $\pm$ 2 parts per million.

2. Absorption of moisture after drying and preceding and during weighing. Under normal conditions of the atmosphere this is not a large factor, but with high humidities samples have been known to gain in weight from 5 to 20 parts per million even during rapid and skillful manipulation.

3. Variations in the action of the filter on the dissolved materials in the water.

Normally Nos. 1 and 2 are very low, and with the best apparatus and careful work they can usually be kept below amounts of serious magnitude; but the variations in the effect of the filter on the dissolved constituents in the sample do not seem to be controllable within a range of $\pm$ 5 parts. In the filtration of waters containing large amounts of very finely divided clay, filter paper is totally inadequate, and a Pasteur filter tube is used. These tubes at times seem to retain to a varying degree dissolved materials from the samples, and at other times these materials seem to be given up to the water passing through the tube.

It will, therefore, be seen that the gravimetric determination, which is our standard of precision, is at all times in doubt by at least 5, and perhaps 10 parts, plus or minus. To a certain extent these errors may balance each other in any one sample, and in a series it is very probable that the average represents the truth very closely.

Rapid Methods of Estimation.

The suspended matters in a water give to it a peculiar appearance called turbidity. It is, therefore, natural that this characteristic should be noted, and for some time analysts have been accustomed to express in some form the "turbidity" of the sample. In some cases this was given as the appearance of the untreated sample, and in others as the appearance of the supernatant liquid after subsidence had taken place for a certain period. In this paper we shall use the term "turbidity" as expressing the appearance of the sample after having been thoroughly shaken. The turbidity is, therefore, due to the presence of suspended matters, but while more or less elaborate means (including those described here) have been used in obtaining a measure of the turbidity, no one, so far as the writers are aware, has heretofore endeavored to establish a relation between the turbidity and the weight of the suspended matters present. Turbidity being an expression of appearance, which is an optical phenomenon, methods for measuring turbidity are naturally of an optical character, and while we may have made some apparent improvements in instruments or in their use, our attention has been practically devoted to the study of the constancy of observations and the interpretation of the turbidity readings in terms of the weight of the suspended matters.

Before taking up the several methods in detail, it will be well to note the leading factors which influence all of the processes, and to consider in a general way the principles upon which these observations are based.

The water which has been studied is that of the Ohio River, the observations dating back to 1896, when considerable work was done at Louisville, Kentucky, but the greater amount of the data was collected at Cincinnati during the fall and early winter of 1898.

The Ohio River water is fairly typical of the most turbid waters of this country, carrying at times great amounts of silt and clay in suspension. It is chiefly characterized by the sudden and great changes which take place in the amount and character of the suspended matters which it contains. Variations of ten fold in one day in the weight of suspended matters are not uncommon, and, judged from their hydraulic subsiding value, nearly as rapid changes take place in their character. Such a water, therefore, represents to a large degree the most extreme conditions under which the turbidity and the weight of suspended

matters may be compared on account of the changes in relation between the character and weight of suspended material. A grain of sand in a liter of water would not cause any turbidity, but if the grain of sand were replaced by an equal weight of millions of submicroscopical clay particles, the water would be decidedly turbid.

Agricultural chemists divide the material deposited from silt- and clay-bearing waters into three classes. These classes, which are noteworthy in this connection as representing the range in size of materials present, are as follows:

Sand.	Particles over 0.05 mm. diameter (hydraulic subsiding value).
Silt.	Particles between 0.05 and 0.005 mm. diameter.
Clay.	Particles less than 0.005 mm. diameter.

When it is borne in mind that each of the above classes is present in constantly varying amounts, it will be readily seen that it would appear extremely doubtful whether any expression or measurement of the appearance of a water could be expressed in terms of the weight of suspended matters present. On the other hand, it is these suspended matters that give the turbidity to the water through which they are distributed in very minute particles under any circumstances; and it was evident from the beginning of these studies that in a general way the greater the turbidity, the greater the weight of suspended matters.

As a part of any complete system of purification for waters carrying large amounts of suspended matters which will settle out readily, there will probably be more or less provision for plain subsidence. This action removes practically all of the sand, most of the silt, and some of the clay, the amounts increasing as the period of subsidence is increased. By this operation the range in character of suspended matters is reduced materially, and for the most part the turbidity of such a water is caused by clay particles only. In connection with the investigations of the Board of Trustees, "Commissioners of Water Works," of Cincinnati, Ohio, plain subsidence was a preliminary step in the systems of purification tested. We have, therefore, extended our study of the relation of turbidity to the weight of suspended matters to the subsided water also; and in the following pages the term "river water" is to be understood to refer to the water as pumped from the Ohio River at Cincinnati, and "subsided water" to refer to the same water after two or three days of plain subsidence,

during which from 60 to 80 per cent. of the suspended matters were removed.

Bearing the above points in mind, four different methods have been studied and are here discussed:

I. The first and simplest method consists in the comparison of the water with standards containing known amounts of suspended matters. These standards are prepared by dilution of water in which the weight of suspended matters has been determined.

II. The second method, which consisted in measuring directly the amount of light absorbed in its passage through the water, involved more or less elaborate apparatus, and has not as yet passed the experimental stage.

III. The third method is a very simple one which has been used for some time as a measure of turbidity — the determination of the vanishing depth of an object, commonly a bright wire.

IV. The fourth method was also the determination of a vanishing depth, but in this case light was transmitted up through the column of liquid and the vanishing object was the edge of the orifice admitting the light.

These methods are taken up and discussed in order.

I. Comparison with Standards.

Ohio River water was allowed to stand for several hours in a large bottle to permit of the sedimentation of the coarser particles. The supernatant liquid containing the finer clay particles was then siphoned off and the weight of the suspended matters carefully determined.

Standards containing varying amounts of suspended matters were prepared by dilution from this water and the samples compared with them in one-half gallon white glass bottles, both by reflected and transmitted light. Comparisons were also made in tubes using natural and artificial light and reflectors of white and of various colors. The light was transmitted up through the tube, and in some experiments side reflection was guarded against by special devices.

A series of experiments was also undertaken to find out the best method of preparing artificial clay standards, particularly for use in comparison with waters imperfectly clarified by filtration in order to estimate the very small quantity of finely divided clay which still remained. Kaolin and various clays were experimented with, and on account of the colored appearance of the water at times due to dis-

solved color and to finely divided oxides of iron, the addition of coloring agents such as methyl orange and caramel solutions was tried.

The result of this work led to the employment of the clay remaining in suspension in the Ohio River water as stated above, and to the use of methyl orange as a coloring agent. The best results were obtained by using Nessler cylinders of white glass, a white reflector, and diffused light. The comparison in bottles was much less accurate than in the tubes, and was soon abandoned.

Water which contains more than 25 parts per million of finely divided suspended clay, when viewed in a glass tube in a depth of 8 inches, is too turbid for the eye to distinguish differences with any accuracy. This method is therefore limited for practical purposes to waters containing less than 25 parts per million of suspended matters. Moreover, since silt and sand so seriously affect the weight of suspended matters without proportionally increasing the turbidity, this method is further limited to waters containing suspended material of a uniform and finely divided character, such as would occur in clay-bearing waters after a number of hours of subsidence, or in such a water imperfectly clarified by filtration.

The Ohio River water usually contains much more material in suspension than the above limit of 25 parts per million, and so this method is normally not applicable. During stages of very low water, however, the river water is freed by deposition in the river of practically all of its silt and sand, and contains for the most part only the finer clay particles. Under these conditions the weight of suspended matters may go below the above limit, and this method become available.

By the proper dilution with clear water of waters containing more than 25 parts per million of suspended matters, or by diminishing the depth of the column of liquid in which comparisons are made, this method would perhaps give approximate results of considerable value. Investigations along this line, however, were not carried far enough to warrant any very definite statements.

In the application of this method to turbid effluents, a series of 110 comparisons between readings with clay standards and the amount of suspended matters determined gravimetrically, showed that in about 25 per cent. of the results, the clay standards gave figures not quite 2 parts per million too high, and in 75 per cent. of the results not quite 5 parts per million too low. In other words, an average varia-

tion from 0–5 parts per million was apparent in comparing the two methods. Individual results showed very much wider differences, but the figures given probably represent approximately the truth.

It should be borne in mind, however, that the gravimetric results with such low amounts (all of them less than 25 parts per million) are as much open to suspicion as the results from comparison, and that the tendency of the gravimetric results to be higher than the others is very likely due to too low figures for the dissolved constituents, thus increasing the apparent amount of suspended matters.

The variation in the color of turbid waters containing small quantities of finely divided clay produced by dissolved vegetable matter and by suspended oxides of iron, is a rather serious difficulty in the use of this method. Coloring the standards so as to compare with the mean average color of the water is about the only remedy which can be applied. It has been found that increasing amounts of color were necessary as the amount of suspended matters in the standards increased. In our experience with Ohio River water, however, the periods covered by irregularities in color have been comparatively short, and no very great difficulty has been found in producing the proper adjustment of the standards.

In conclusion, it is believed that this method of comparison, carried out as described, will give on similar waters, as it has here, a satisfactory means of estimating the weight of finely divided suspended matters when present in amounts not exceeding 25 parts per million.

II. Photo–Comparator.

This instrument seems to have first been used extensively by James A. Seddon, C. E., in sedimentation studies at St. Louis, and is referred to in the *Journal of the Association of Engineering Societies* for 1889, Vol. VIII, page 477. It consists essentially of three parts, a glass cell to hold the water to be observed, two lights, and a photometer disk. These three parts are enclosed in a light-tight compartment or room, and so arranged that rays from one of the lights pass through the water in the glass cell. The photometer disk is placed between the water and the other light, and by finding the point where both sides of the disk are equally illuminated, the relative intensities of the rays from the two lights are measured. Comparisons with and without water in the glass compartment give the decrease in intensity of the light rays in passing through the water.

In our studies two Welsbach gas lights of about 50 candle power each were used. For holding the water wooden boxes with thin glass ends were employed, and the disk used was a standard Leeson disk. Several different cells were employed, varying from 0.25 to 3.0 inches in length of water section. Considerable difficulty was experienced in using this instrument, due in the main to the following factors:

1. It was found that variations in the relative strengths of the lights used were very large. Differences of 10 per cent. were obtained in a series of ten readings made within 15 to 20 minutes, while variations as high as 22 per cent. and 33 per cent. were noted on allowing an hour to intervene between two sets of readings, and on successive days, respectively. The latter figures are extreme, and probably 10 to 15 per cent. would represent the average fluctuation.

2. The absorption of the light rays by the water reduced the illumination of the disk. This necessitated the use of very thin strata of water when it was very turbid. It was evident that in order to maintain a sufficient illumination of the disk to determine clearly the end point, several different water cells of varying depths would be required, and possibly lights of different intensities. The intervention of the empty cell, and also of the cell filled with distilled water had very appreciable effects on the relative intensities of the lights. This amounted to from 8 to 24 per cent. for the effect of the cell alone, and to from 10 to 30 per cent. for the effect of the cell filled with distilled water.

3. As the amount of suspended matters increased in the samples examined, a new factor appeared. The light rays emerging from the water cell became more and more scattered and were so extremely divergent that they seriously affected the distinctness of the vanishing point of the star on the disk.

4. For different waters different distances between the sources of light might be advisable. With water containing relatively low amounts of suspended matters, the base line used in this instrument, 100 inches, was apparently quite satisfactory, but with more turbid waters it was evidently too long to maintain a sufficient illumination of the disk for satisfactory observation.

5. It appeared that subsidence in the cell during the reading of the strength of the light rays might cause a marked reduction in the amount of suspended matters in the sample, and the estimation would, therefore, be too low.

With the device as constructed, our preliminary experiments indicated that quite small differences in the amount of suspended matters could be detected. A series of samples in which the suspended matters ranged between 60 and 800 parts per million, and where the thickness of the stratum employed was one-half inch, showed that differences of less than 10 parts per million could not be readily distinguished. If, however, the thickness of the stratum was increased when estimating low amounts of suspended matters, very much better results could be obtained, as was shown by using cells from 1 to 3 inches in length.

It was evident that quite extended study would be required to establish clearly the best details for the device in order to put it into practical shape. This fact combined with the cumbersome character of the instrument and the development of information along other lines, which promised more immediate results, caused us to discontinue temporarily its further study. It should be pointed out, however, that the difficulties all appear capable of solution and that our limited study of the instrument should only be regarded as preliminary.

III. Wire Method.

This method is said to have been used in Europe for some time, and was first employed in this country, so far as our definite knowledge goes, about ten years ago, at the Lawrence Experiment Station[1] as a measure of the turbidity of sewage. It consists in the determination of the depth of liquid through which a small bright wire can be seen. The method has not been used enough to establish any standard procedure, so we have employed both a platinum and a copper wire of about .012 inch in diameter (No. 30 B. W. G.) and about 1 inch long. The wire was attached to the end of a measuring rod, and when used was simply immersed in the water, the depth at which the wire disappeared being read off on the rod. The readings were made in vessels of varying shape and capacity in diffused light, (*i. e.*, not in direct sun light).

The first question that was considered was the possibility of a direct and simple relation between the weight of suspended matters and the turbidity reading (which was recorded as the reciprocal of the vanishing depth in inches), when the suspended matters were all of

[1] Report Massachusetts State Board of Health, 1890, Vol. II.

the same general character. For this purpose several experiments were made, of which the following table is representative, the various samples having been obtained by successive dilutions.

Weight of suspended matters. (Parts per million.)	Turbidity.	Weight divided by turbidity.
33	0.17	195
62	0.30	198
126	0.49	252
248	0.86	275
342	1.02	335
453	1.14	344
528	1.43	370
634	1.73	368
792	2.00	396
1,057	2.67	391
1,585	3.13	507

These data show clearly that no direct relation existed between the weight and the turbidity, but in a general way they seemed to follow the same curve. This was sufficiently interesting and suggestive to warrant the collection of more data, and, accordingly, observations were made regularly upon the river water and upon the subsided water. The first question which arises in the study of the observations is this: Does the same turbidity reading always indicate the same amount of suspended matters, and if not, what is the range?

The following table was compiled from observations made on river water. All of the observations were arranged according to turbidity readings, and where more than two similar readings had been made, the corresponding weights of suspended matters (determined gravimetrically) were averaged, and the percentages which the maximum and minimum weights in each case were of the average, were determined.

These data show that a turbidity reading did not necessarily mean the same weight of suspended material, but that for the same readings differences of from $+42$ to -54 per cent. of the average might be found. On the average the range was from $+17$ to -21 per cent.

TABLE SHOWING THE RANGE IN WEIGHT OF SUSPENDED MATTERS IN OHIO RIVER WATER FOR THE SAME TURBIDITIES.

Turbidity.	Average weight of suspended matters. (Parts per million.)	Percentage which the maximum weight was of the average.	Percentage which the minimum weight was of the average.
0.20	49	130	71
0.21	64	123	61
0.22	45	120	82
0.28	75	101	96
0.40	122	123	77
0.45	116	107	94
0.47	195	101	99
0.50	143	142	46
0.57	211	105	82
0.67	223	121	80
0.80	278	113	70
0.89	267	117	82
1.00	334	117	82
2.00	766	120	79

In a similar manner the results on subsided water have been averaged, and show a range of from + 28 to — 32 per cent., the average range being + 10 to — 15 per cent.

TABLE SHOWING THE RANGE IN WEIGHT OF SUSPENDED MATTERS IN SUBSIDED WATER FOR THE SAME TURBIDITIES.

Turbidity.	Average weight of suspended matters. (Parts per million.)	Percentage which the maximum weight was of the average.	Percentage which the minimum weight was of the average.
0.11	16	100	100
0.12	14	128	71
0.19	20	115	80
0.28	35	114	86
0.29	50	100	100
0.33	53	107	85
0.36	85	107	91
0.50	89	107	84
1.00	172	116	68

From these tables certain facts are clearly brought out. The first one is that while at times the actual amount of suspended matters may differ considerably from that which would be indicated on the average by any turbidity reading, yet, practically speaking, the turbidity observations can be translated in terms of weight of suspended matters with an accuracy which, all things considered, is quite remarkable.

The second fact is that the same turbidity reading does not represent anything like the same amount of suspended material in a subsided water that it does before subsidence has taken place; in fact, the ratio is almost exactly twofold.

Finally, it is evident that in a general way increased turbidities mean increased material in suspension, but not in a uniform manner.

These topics will all be taken up again under the discussion of the diaphanometer, and there are only presented further in direct connection with the wire method some special comments on the difficulties in the application of the method.

The first and most important difficulty is the strength and character of the light. In this method light rays pass downward through the water, and a certain number of them are reflected upward again to the eye. A limiting point is attained when a sufficient number no longer reach the eye to define the outlines of the wire. The number of rays which pass to the eye is of course dependent on the number of rays entering the water, and their strength and direction. For this purpose (as the reflection from the surface of rays from a direct source of light would blind the eye) diffused, *i. e.*, not direct, sunlight seems most suitable. Its strength is, however, not controllable, and it is not available save for a small percentage of the time on clear days and not at all on cloudy ones or at night. These reasons alone made the method much less desirable than one in which the conditions were capable of better control.

Naturally, the suspended material must be well distributed through the water before observations are taken, but as a large surface is required in order to admit all of the light rays (limitations of area would have different percentage effects for different depths), rather large receptacles are necessary in which to make the observations. Under these conditions it is very difficult to insure thorough mixing of the samples, and not start up a wave motion which prevents the passage of light through the surface of the liquid. This difficulty could, however, be controlled by construction of a special compartment through which the water was kept flowing.

Finally, it is essential that a wire of the same size and character of surface should be used for all observations.

The only one of these points not capable of ready solution seemed to be the source of light, and on this account our attention was directed more and more to instruments and methods in which the source of light could be controlled within reasonable limits. The preliminary work on the photo-comparator has already been presented, and the work on the fourth method in which, like the photo-comparator, the light was artificial, will now be considered.

IV. Diaphanometer.

This instrument consists essentially of a tube with a transparent diaphragm at the lower end. Light is reflected up through this tube, and water is admitted until an image painted on the diaphragm just disappears. The reciprocal of the depth is taken as the turbidity reading, and corresponds in a general way with the turbidity reading by the wire method. This general device or method was used quite extensively by George Hornung, C. E., in studies made upon Ohio River water at Newport, Kentucky, during 1876 and 1877.[1]

Experiments were made by the writers during the course of several years of more or less regular use of this instrument with tubes of metal and glass, with various forms of diaphragm and with different kinds of light. These studies developed certain apparent principles upon which the present form of instrument is based.

1. The distinctness or sharpness with which the image loses its form is increased as the intensity of the light is increased, the most satisfactory vanishing points having been found with directly reflected sunlight.

2. It is essential that the intensity of the light be practically constant and uniform at all times.

3. The most satisfactory image, as determined by the distinctness of the vanishing depth, is a small transparent cross on a dark field.

4. With the metal tube the inside of the tube should be dull, not bright, but need not necessarily be painted.

In its present form, the device consists of a copper tube 1.375 inches in diameter, and 49.75 inches long. At the bottom of this tube is a glass diaphragm which is partially painted on its under side. The unpainted portion of the diaphragm forms a cross of two lines,

[1] See Report of Engineer and Superintendent of Newport Water Works for 1876. Method and apparatus described in a paper read before Cincinnati Society of Civil Engineers in March, 1896. Abstract of paper given in *Engineering News*, April 2, 1896.

each 1 millimeter wide, crossing in the center and extending to the edge of the disk.

The light used is from a Welsbach gas lamp of about 50 candle power. The rays of light from the lamp are condensed by a 4-inch double plano-convex condenser of about 12 diameters magnification. The light is reflected up through the tube by means of a plane mirror.

The lamp, condenser, and mirror are inclosed in a plain wooden box painted black on the inside and provided with suitable ventilating arrangements. The diaphanometer tube is inserted through an opening in this box, in which it fits closely and rests upon a shoulder with the diaphragm about 2 inches above the mirror.

The tube is easily removable, and for the purpose of observation is set into the box empty, and the water to be examined is poured in at the top until the depth is sufficient to cause the semblance of the cross to be entirely lost. With a little experience this end point is readily determined with most waters. A series of independent readings by different observers indicated that the error due to personal equation was not more than $\pm$ 2.5 per cent. The depth of the water is determined from the volume introduced by its relation to the capacity of the tube.

The first series of observations made with this instrument for the purposes set forth in the introduction to this paper (the device having been used more or less as a measure of turbidity since early in 1896) was on the same set of dilution samples as were recorded under the wire method. As mentioned there, these samples were made by dilution of a very turbid water in the endeavor to determine whether any constant and simple relation existed between turbidity readings and weight determinations. This series gave the following results:

Weight of suspended matters. (Parts per million.)	Turbidity.	Weight divided by turbidity.
33	0.07	465
62	0.13	484
126	0.21	583
248	0.38	657
342	0.46	745
453	0.55	820
528	0.62	855
634	0.70	900
792	0.82	974
1,057	1.18	898
1,585	1.73	919

As in the case of the wire method, these results clearly indicated that there was no direct and simple mathematical relation between the two observations. It therefore became a question to determine the constancy of the meaning of a turbidity reading, as in the case of the wire method. For this purpose observations were continued on river water and subsided water for several months, and then all of the weights determined for any turbidity reading were averaged, and the range of weights for the same reading determined. These results are given for river water and subsided water in the following tables:

TABLE SHOWING THE RANGE IN WEIGHT OF SUSPENDED MATTERS IN OHIO RIVER WATER FOR THE SAME TURBIDITIES.

Turbidity.	Average weight of suspended matters. (Parts per million.)	Percentage which the maximum weight was of the average.	Percentage which the minimum weight was of the average.
0.049	28	100	100
0.050	40	102	95
0.052	48	104	96
0.066	52	121	77
0.070	55	125	73
0.087	61	123	75
0.115	117	112	93
0.154	137	114	85
0.172	208	116	86
0.200	184	101	98
0.217	222	111	92
0.238	308	108	91
0.278	312	125	85
0.286	382	103	96
0.322	495	121	76
0.345	676	137	63
0.476	535	100	100

This shows an extreme range of from + 37 to — 37 per cent. with an average range of from + 13 to — 12 per cent.

TABLE SHOWING THE RANGE IN WEIGHT OF SUSPENDED MATTERS IN SUBSIDED WATER FOR THE SAME TURBIDITIES.

Turbidity.	Average weight of suspended matters. (Parts per million.)	Percentage which the maximum weight was of the average.	Percentage which the minimum weight was of the average.
0.050	24	116	83
0.052	25	116	80
0.055	27	100	100
0.058	26	134	80
0.063	27	103	96
0.064	25	120	84
0.067	26	115	88
0.069	32	112	84
0.070	30	103	90
0.071	31	106	93
0.077	36	108	89
0.083	43	111	90
0.105	52	111	90
0.137	75	109	89
0.172	99	107	92
0.238	133	120	90
0.250	125	113	81
0.263	152	109	93
0.278	156	112	97
0.385	220	102	97
0.417	256	100	100

The data on subsided water show an extreme range of from + 34 to — 20 per cent., with an average range of from + 10 to — 11 per cent.

As stated under the discussion of the wire method, these results are sufficiently close to be of practical value as an estimation of the weight of the suspended matters present. In fact, as will be presented later, the actual use of the method shows that in a large majority of the cases the variations are not as great as would be indicated by the

above figures. We, therefore, sought first to determine in how far the normal range of character of suspended matters represented the range which might take place under extreme conditions, and as to whether the mixture of coarse and fine particles affected the relation mathematically, or whether there was some other factor present. The following table shows the quotients obtained by dividing the weight of suspended matters by the turbidity readings in each of three sets of samples. The first series of samples contained coarse suspended material obtained by sedimentation of muddy Ohio River water. The second series was from the supernatant water after sedimentation and contained very fine material, and the third set was from the original water.

Weight of Suspended matters. (Parts per million.)	Weight of Suspended Matters Divided by Turbidity.		
	Coarse material.	Fine material.	Mixture.
50	740	615	690
100	750	630	740
150	840	735	780
200	920	760	820
250	975	825	825
300	1,050	930	935
350	1,120	945	980
400	1,200	960	1,040

It will be seen that the fine material gave considerably higher turbidity readings than the coarse, and that the mixture was approximately the mean of the two. That the mixture was so nearly the mean indicates that the fine material exerted a much stronger influence on the turbidity reading than did the coarse material, for in the original water these materials were mixed in the proportion of about 4 parts by weight of coarse to 1 of fine. This explains the constancy of the turbidities as translated in terms of the weight of suspended matters. The fine material is the controlling factor, and a considerable addition of coarse material exerts but little influence in the turbidity reading.

There has now been presented an outline of the preliminary studies along the above lines, and it remains simply to record the practical application of the conclusions to which they led.

For reasons which were incidental to the operation of the experimental purification plant at Cincinnati, practical use of some means of estimating quickly the weight of suspended matters in the water after subsidence was very desirable, but it was not essential to make such estimations on the original river water. The following data apply, therefore, to subsided water only. The reasons for using the "diaphanometer" and "comparison with clay standards" methods were their equally satisfactory, if not greater degree of constancy as compared with other methods, and their great simplicity, ease of manipulation, and the control of the variables.

During the last four months of 1898, regular turbidity readings by the diaphanometer were made on subsided water, and these were translated into equivalent weights. At first this was done by a curve obtained from average readings and weight determinations. Later, however, this curve was sufficiently strengthened to obtain its equation. No apparently rational formula could be obtained to agree with the facts, largely, it is believed, on account of the complex character of the optical laws which apply to the method. A straight line formula of the form Weight = Constant (Turbidity — Constant′) was found to fit the observations very well, and the most probable constants were found by the method of least squares to be 600 and 0.01. Accordingly from early in October, all turbidity readings were translated into equivalent weights by this formula:

$$\text{Weight in parts per million} = 600\ (\text{Turbidity} - 0.01).$$

The results obtained in this way seemed to agree very well with actual determinations of weight. Below 25 parts per million, however, it was found that the length of the column of water became so great that the image was greatly reduced in size by the refraction of the meniscus, and its distinctness was largely impaired by what was apparently the effect of the water alone. Reliance was, therefore, placed in regular work on the comparison with standards below 25 parts per million, and on turbidity readings by the diaphanometer above this point.

The following tables have been prepared to show the relation between the estimated weights and the actual gravimetric determina-

tions. The observations are grouped in several sets for convenience in study, according to the parts per million of suspended matters.

WEIGHT OF SUSPENDED MATTERS IN PARTS PER MILLION IN SUBSIDED WATER.

GROUP.	No. of observations.	DETERMINED GRAVIMETRICALLY.			ESTIMATED BY DIAPHANOMETER.		
		Maximum.	Minimum.	Average.	Maximum.*	Minimum.*	Average.
25– 50 parts.	33	49	26	34	49	32	37
51–100 parts.	43	98	53	69	96	43	72
101–200 parts.	38	178	106	130	180	98	137
201–300 parts.	14	292	214	240	266	215	230

*On the same water as the maximum and minimum gravimetric determinations.

The following table brings out more distinctly the actual variations between the estimated and determined weights.

NUMBER OF TIMES WHEN THE ESTIMATED WEIGHT OF SUSPENDED MATTERS DIFFERED FROM THE GRAVIMETRIC DETERMINATION BY VARIOUS AMOUNTS.

GROUP.	NUMBER OF TIMES WHEN THE VARIATION WAS THE FOLLOWING AMOUNTS IN PARTS PER MILLION.				Average variation in parts per million.
Parts per million.	0 — 5	6 — 10	11 — 15	16 — 25	
Between 25 and 50 parts . .	21	10	2	0	3
Between 50 and 100 parts . .	20	16	7	1	1
Between 100 and 200 parts* .	18	14	4	2	9
Between 200 and 300 parts† .	2	4	4	3	14
Totals	61	44	17	6	..

* Four pairs of observations which are not included in the above, differed by 38, 39, 43 and 52 parts, respectively, the estimated weight being below the gravimetric weight by that amount. These were unquestionably due to particles of very heavy material not normally present in the water.

† One pair of observations differed by 27 parts, and is included in the average.

CONCLUSIONS.

The result of the study of the several methods may be summarized as follows:

1. The study of these methods has only been in connection with their application to the Ohio River water at Cincinnati before and

after sedimentation. This water, however, may be considered fairly typical of the muddy waters of this portion of the country, and the conclusions which are drawn are, therefore, probably true for this general class of waters.

2. By the method of comparison with standard clay solutions reasonably close estimations may be made of the weight of very finely divided suspended matters when they are present in amounts of less than 25 parts per million.

3. With regard to the photo-comparator, the studies were not advanced far enough to draw very definite conclusions, but after the solution of the essential details of the instrument it seems that this method might be made of value.

4. The wire method as now employed, is seriously handicapped by the question of the variation of light. In the absence of other methods, estimations could be made in this manner which would be of considerable value; and it seems possible that by certain modifications, such as the use of a water glass and artificial light, the conditions might be made equally as satisfactory as with the diaphanometer.

5. With waters containing more than 25 parts per million of suspended matters, the diaphanometer seems to give readings which can be translated in terms of weight of suspended matters with normally but a comparatively small error.

6. It must be borne in mind that the estimation of the weight of suspended matters by any of the above methods, is based upon the relation which the turbidity of the water bears to the weight of suspended matters present. If these matters are fairly uniform in character and the particles do not vary widely in size, then the above methods are accurate within reasonable limits, but as the suspended material becomes more varied in character, the particles differing widely as to size and specific gravity, then the greater becomes the error by any of the above methods, and the less reliance can be placed upon them.

7. Finally, the great convenience and rapidity with which fairly reliable results may be obtained by any of the four methods described, after careful standardization against the gravimetric method, are features which strongly commend them to persons requiring in practical work the class of information which they furnish.

LABORATORY OF COMMISSIONERS OF WATER WORKS,
Cincinnati, January 31, 1899.

ON THE DETERMINATION OF ADDED WATER IN MILK.

By A. G. WOODMAN.

In order to estimate the amount of water which has been added to a sample of milk it is generally necessary to make separate determinations of the specific gravity, the total solids, and the fat. The accurate determination of at least two of these factors is a matter of considerable time, and although it is possible to shorten the time to a certain extent by the use of such formulæ as those of Fleischmann, or of Hehner and Richmond, there can be no doubt that a rapid, and at the same time accurate method for determining the extent to which milk has been watered would find extensive application.

The most successful of the various methods by which it has been proposed to effect the direct determination of added water are based in general on the fact that under certain conditions the serum, or liquid portion of sour milk, possesses a fairly constant composition, much more so than the milk itself. The methods by which the milk serum is obtained depend for the most part upon the coagulation of the milk by dilute acid. Vieth[1] recommends letting the milk sour spontaneously by standing at the room temperature for two or three days, and then separating the serum from the coagulum at 65° C. Other investigators prefer to coagulate the milk directly by the addition of an acid. Dietsch[2] and Radulescu[3] use dilute acetic acid and warm the milk to a fairly low temperature. Reich[4] recommends the use of a small quantity of glacial acetic acid and final heating of the milk to 100° C. Sambuc[5] heats the milk to 40°–50° C. with 2 cc. of an alcoholic solution of tartaric acid of a specific gravity of 1.030–1.032, approximately the same as that of the milk serum itself. The whole question has been investigated quite thoroughly by Radulescu,

[1] Forschungen auf dem Gebiete der Viehhaltung und ihrer Erzeugnisse, 1884 (15), 334.
[2] Chem. Ztg., 1884, 323.
[3] Mitt. aus dem pharm. Ins. u. Labor. für ang. Chem. der Univ. Erlangen, 1890, III, 93.
[4] Milch-Ztg., 1892, 274.
[5] Jour. de Pharm. et de Chim., 1884, 95.

who has made a study of the conditions necessary in regard to the strength of acetic acid employed, the temperature to which the mixture should be heated, and the time required in order to obtain satisfactory results. The method recommended by Radulescu is as follows: To 100 cc. of the milk is added 2 cc. of 20 per cent. acetic acid, and the mixture is heated in a water bath at 85° C. for 5–10 minutes, as a result of which the casein separates in the form of a compact cake, and is easily filtered off. After being thoroughly mixed the filtrate is cooled to 15° C., and its specific gravity taken. The acid used is variously stated in different portions of Radulescu's paper to be 20 per cent. acetic acid, 25 per cent. acetic acid, and acetic acid having a specific gravity of 1.0294, which is about 22 per cent. strength. In the determinations which have been carried out, using practically the same method as that proposed by Radulescu, it has been found that for the richer samples of milk the 20 per cent. acid is too dilute, failing to entirely precipitate the casein, but that the acid of 25 per cent. strength is sufficient in all cases.

After a number of experiments, following at first as nearly as possible the procedure recommended by Radulescu, subsequently making such modifications in the method as were found advisable in order to secure more nearly uniform results, the following procedure has been adopted in the present investigation: 100 cc. of the milk, which should be at a temperature of about 20° C., is thoroughly mixed with 2 cc. of a 25 per cent. solution of acetic acid, specific gravity 1.0350, in a small beaker. The beakers, kept covered with watch glasses, are heated for 20 minutes in a water bath maintained at a temperature of 70° C., the temperature of the milk samples being brought gradually by this means to about 65° C. The beakers are then removed from the water bath and placed immediately in ice water, where they are allowed to remain for 10 or 15 minutes, after which the samples are filtered through small, dry, plaited filters, the first portion of the filtrate, which generally comes through cloudy, being returned to the filter. After the filtrate has been thoroughly mixed it is cooled to 15° C., and its specific gravity taken by means of a Westphal balance. It occasionally happens, more especially with normal milk, or milk to which only a slight amount of water has been added, that the milk serum which is thus obtained has a slight cloudiness or opalescence, but it has not been observed to cause any appreciable difference in the specific gravity. For assistance in studying the conditions upon which the above

procedure is based, credit is due to Mr. J. W. Brown and Miss J. H. Bartlett.

In the following table (Table I) will be found the results obtained on samples of pure milk obtained from various sources, and on mixtures of these milks containing varying percentages of water, by the method that has been outlined above. All determinations of specific gravity have been made at 15° C., using a delicate Westphal balance which gave the specific gravity of pure water at 15° as 0.0000.

TABLE I.

	Specific Gravity of						
	Milk.	Serum.					
No.		Normal.	10% water.	20% water.	30% water.	40% water.	50% water.
1.	1.0337	1.0297	1.0263	1.0237	1.0206	1.0180	1.0153
2.	1.0334	1.0294	1.0260	1.0232	1.0203	1.0174	1.0151
3.	1.0340	1.0295	1.0264	1.0232	1.0206	1.0175	1.0151
4.	1.0324	1.0293	1.0259	1.0233	1.0202	1.0178	1.0148
5.	1.0336	1.0296	1.0262	1.0235	1.0205	1.0177	1.0153
6.	1.0328	1.0293	1.0258	1.0233	1.0202	1.0174	1.0148
7.	1.0334	1.0292	1.0260	1.0233	1.0202	1.0175	1.0149
8.	1.0325	1.0294	1.0260	1.0234	1.0201	1.0175	1.0152
9.	1.0339	1.0296	1.0262	1.0236	1.0206	1.0178	1.0153
10.	1.0335	1.0296	1.0261	1.0235	1.0204	1.0174	1.0148
11.	1.0329	1.0292	1.0259	1.0234	1.0203	1.0173	1.0148
Av.	1.0335	1.0294	1.0261	1.0234	1.0204	1.0175	1.0150

The specific gravity of the serum from milk at a given dilution is shown by the table to be a fairly constant quantity, the average decrease for each 10 per cent. of water being .0031.

The specific gravities given in Table I were obtained on samples in which the percentage of water *in the mixture* varied by ten. As might naturally be expected, if the results are calculated on the basis of the percentage of *added* water, the differences in specific gravity are not so great. In Table II are given the results obtained on samples of pure milk to which varying percentages of water have been added.

TABLE II.

Samples varying by 10 per cent. *added* water.

	Specific Gravity of						
	Milk.	Serum.					
No.		Normal.	10% water.	20% water.	30% water.	40% water.	50% water.
1.	1.0336	1.0294	1.0259	1.0239	1.0219	1.0199	1.0189
2.	1.0333	1.0295	1.0260	1.0240	1.0220	1.0200	1.0190
3.	1.0334	1.0294	1.0259	1.0239	1.0220	1.0200	1.0190
4.	1.0330	1.0295	1.0260	1.0239	1.0221	1.0201	1.0190
5.	1.0324	1.0294	1.0259	1.0239	1.0220	1.0199	1.0190
6.	1.0328	1.0294	1.0260	1.0239	1.0220	1.0200	1.0190
7.	1.0340	1.0294	1.0260	1.0239	1.0220	1.0200	1.0190
8.	1.0337	1.0296	1.0261	1.0240	1.0221	1.0201	1.0190
9.	1.0330	1.0294	1.0259	1.0239	1.0221	1.0200	1.0190
10.	1.0335	1.0295	1.0260	1.0239	1.0220	1.0199	1.0189
Av.	1.03327	1.02945	1.02597	1.02392	1.02202	1.01999	1.01898

These results confirm the conclusion reached by Radulescu that the specific gravity of the serum from normal milk is never below 1.027, and in no case of those examined was it found to be below 1.0290. The decrease in specific gravity caused by the addition of 10 per cent. of water varied from 0.0035 to 0.0010. The statement is made by Radulescu (*loc. cit.*) that the addition of each 10 per cent. of water to normal milk lowers the specific gravity of the serum by 0.0005 to 0.0010, and this value is also found in text books which treat of the subject, for example, in König.[1] This would seem to be due to some clerical error, for from the preceding table it will be seen that the decrease actually obtained is considerably higher, and as a matter of fact the differences shown in Radulescu's tabulation of results vary from 0.0029 to 0.0012. Radulescu further recommends to determine the total amount of solids, and also the fat in the milk serum; but this does not seem to me to be advisable, because if it is done, the method offers no special advantages as regards economy of time and ease of execution over those ordinarily used.

[1] Die Untersuchung landwirtschaftlich und gewerblich wichtiger Stoffe. Ed. 1898, 361.

The method as originally proposed by Radulescu has been criticized by Reich[2] on the ground that only a partial clarification of the milk is effected, the precipitation and removal of the albumen not being complete at the temperature to which the milk is heated. The following modification of the method has been proposed by Reich: 100 cc. of the milk is thoroughly shaken in a 200 cc. flask with 0.4 cc. of glacial acetic acid, the mixture heated for 5–6 minutes at 60–65° C., cooled and the liquid portion poured off into 50 cc. Erlenmeyer flasks. These are hung for 5–6 minutes in a bath of boiling water, then rapidly cooled in ice water. The casein and albumen are removed by filtering through a small dry Swedish filter and the specific gravity of the filtrate taken at 15° C. The specific gravity of the serum from five samples of milk diluted with varying percentages of water has been determined by Reich's method, and also of the same samples by the modification of Radulescu's method previously described. These results are given in the following table.

TABLE III.

	Specific Gravity of						
	Milk.	Serum.					
No.		Normal.	10% water.	20% water.	30% water.	40% water.	50% water.
	(*a*) According to the modified Radulescu method.						
1.	1.0337	1.0294	1.0259	1.0239	1.0220	1.0199	1.0190
2.	1.0319	1.0294	1.0260	1.0240	1.0220	1.0199	1.0190
3.	1.0338	1.0295	1.0260	1.0239	1.0220	1.0200	1.0189
4.	1.0340	1.0294	1.0259	1.0239	1.0219	1.0200	1.0189
5.	1.0328	1.0294	1.0260	1.0240	1.0220	1.0200	1.0190
	(*b*) According to Reich's method.						
1.	1.0337	1.0293	1.0266	1.0240	1.0224	1.0205	1.0196
2.	1.0319	1.0289	1.0257	1.0234	1.0219	1.0200	1.0182
3.	1.0338	1.0292	1.0264	1.0245	1.0226	1.0207	1.0199
4.	1.0340	1.0296	1.0264	1.0243	1.0225	1.0205	1.0198
5.	1.0328	1.0295	1.0270	1.0247	1.0217	1.0210	1.0199

[2] Milch-Ztg., 1892, 274.

The claim of Reich that his method yields concordant results which are uniformly lower than those obtained by Radulescu's method is not borne out by the results shown in Table III. It has been found by experience that the method offers no advantages over that of Radulescu, being more tedious to carry out, and giving results which differ more widely.

As an illustration of the degree of accuracy with which the amount of added water in milk can be estimated from the specific gravity of the milk serum, may be given the following results obtained on two samples purchased at a city grocery, and supposed to be pure milk.

	1.	2.
Specific gravity of milk	1.0282	1.0263
Specific gravity of serum	1.0257	1.0234

The specific gravity of the serum indicated in one case 10 per cent., and in the other 20 per cent. of added water. The amount of added water calculated from careful determinations of the total solids and of the fat was very close to this, being 9.8 per cent. for the first sample, and 19.6 per cent. for the second.

The method as described has been found easy to carry out, and capable of yielding satisfactory results. As a quick method for the estimation of the extent to which milk has been watered, it should prove of considerable value, this being undoubtedly the most common method for the adulteration of milk.

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MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

ASSAYING TELLURIDE ORES FOR GOLD.

By RICHARD W. LODGE.

Received April 15, 1899.

At one time the scorification method was considered the only correct one to use on ores of this character. Recently numerous papers have been published in regard to the correct method of assaying such ores, and many different charges and methods have been suggested. No doubt all of these have their advocates, and in their hands satisfactory results may be obtained; but my own experience is that a rich gold ore containing tellurium can be assayed by either the scorification or crucible method with equally satisfactory results, always provided that the ore has been ground to a sufficient degree of fineness. For the majority of rich ores this is not less than what will pass through a 140-mesh sieve, or finer if possible. In other words, the richer the ore, the finer the sieve should be through which it should be passed.

The following experiments, made by Mr. A. L. Davis, a graduate of 1898 in our course of Mining Engineering, may be of interest to assayers, and may illustrate some of the points it is desired to bring out. These experiments were made in 1897, and carried out in a most thorough and careful manner. The ore selected for the work came from Boulder County, Colorado, and gave a strong test for tellurium. The percentage was not determined. The gangue was chiefly quartz with tellurides and pyrite scattered through it. It was pulverized and passed through a 100-mesh sieve. Assays made by myself showed $68\frac{6}{10}$ ounces gold by the scorification method, and $68\frac{3}{10}$ ounces gold by the crucible method of assay, no correction being made for gold left in slag and cupel. The ore had a reducing power of $1\frac{2}{10}$.

In the experiments carried out by Mr. Davis four different crucible charges were tried, and three different scorification charges. In each experiment the slags and cupels were saved, ground separately and assayed, in order to trace the loss of gold if there was any. The

results are shown in the accompanying tables. From the tables it will be seen that, in the scorification process, some gold is always lost in the slag, and that it is larger than the loss sustained in cupellation, which of course is the rule in gold assays. In the crucible process there is also a loss of gold in the slag, but the percentage loss seems to be less than that sustained in cupellation.

As the ore carried very little silver, enough pure silver was added to all the lead buttons at the time of cupellation to part the resultant bead. It may be of interest to state that tests upon the bone ash from which the cupels were made by us showed that

3.5% would remain on a 60-mesh sieve.
15.9% would pass 60 and remain on 80.
27.8% would pass 80 and remain on 100.
52.8% would pass through 100 mesh sieve.

SCORIFICATION METHOD.

Charges.	No. of experiments.	Wt. of lead button.	Wt. after rescorifying. Wt. after 3d scorification.	Wt. of gold after parting (grammes.)	Gold found in slag.	Gold found in cupel.	Total gold.	Ounces per ton.	Per cent. of total gold found in slag.	Per cent. of total gold found in cupel.
I. Ore $\frac{1}{10}$ A. T.	*1a*	30	20 —	.00622	.00005	.00004	.00631	$63\frac{1}{10}$	.79%	.63%
I. Gran. lead, 60 grams	*2b*	30	Cupelled.	.00648	——	——	——	$64\frac{8}{10}$	—	—
I. ($\frac{1}{2}$ mixed with ore, $\frac{1}{2}$ placed on top)	*3c*	31	Cupelled.	.00690	Trace.	Trace.	.00690	69	.00	00
Borax glass, a pinch on top of all.										
II. Ore $\frac{1}{10}$ A. T.	*1e*	34	22 —	.00686	.00004	None.	.00690	69	.58%	None.
II. Gran. lead, 45 grams. ($\frac{1}{2}$ mixed with ore.)	*2f*	25	Cupelled.	.00648	.00005	.00005	.00658	$65\frac{8}{10}$	.76%	.76%
II. PbO cover 10 grams	*3g*	25	Cupelled.	.00650	.00010	.00006	.00666	$66\frac{6}{10}$	1.50%	.90%
Borax glass, 0.3 grams on top of all.										
III. Ore $\frac{1}{10}$ A. T.	*1h*	48	37 20	.00684	.00005	None.	.00689	$68\frac{9}{10}$	.71%	None.
III. Gran. lead, 60 grams	*2j*	49	25 —	.00647	Trace.	.00005	.00652	$65\frac{2}{10}$	.00	.77%
III. PbO 1 A. T.										

Assays *a*, *e*, and *h* were all made at the same time and under conditions as nearly alike as possible.
Assays *b*, *f*, and *j* were all made at the same time and under like conditions.

CRUCIBLE METHOD.

	Charges.	No. of experiments.	Weight of lead.	Wt. after scorifying once.	Wt. after scorifying twice.	Wt. of gold obtained in grams.	Wt. of gold found in slag.	Wt. of gold found in cupel.	Total gold accounted for.	Ounces per ton.	Per cent. of total gold found in slag.	Per cent. of total gold found in cupel.
I. Mix.	Ore ½ A. T.											
	Soda 60 grams											
	PbO 120 grams	1	30	—	—	.03391	.00007	.00008	.03406	$68\frac{12}{100}$	.21%	.23%
	Argols 1 gram	2	27	—	—						.56%	—
	Borax glass cover.					.03417	.00019	Lost.	.03436	$68\frac{72}{100}$		
II. Mix.	Ore ½ A. T.											
	Soda 20 grams											
	PbO 80 grams	1	80	47	21	.03463	None.	None.			None.	None.
	Gran. Pb, 50 grams								.03463	$69\frac{26}{100}$		
	Argols 1 gram	2	75	51	25	.03387	.00008	.00012			.24%	.35%
	Cover of salt.								.03407	$68\frac{14}{100}$		
III. Mix.	Ore ½ A. T.											
	Soda 40 grams											
	PbO 60 grams	1	29	—	—	.03393	Trace.	.00008	.03401	68.02	—	.24%
	Borax glass 15 grams											
	Argols 1 gram	2	25	—	—	.03414	.00005	.00014	.03433	$68\frac{66}{100}$	.15%	.41%
	Cover of salt.	3	25	—	—	.03401	Trace.	.00016	.03417	$68\frac{34}{100}$	—	.46%
IV. Mix.	Ore 1 A. T.											
	Soda 60 grams											
	Borax glass 15 grams	1	25	—	—	.06698	.00009	.00005	.06712	$67\frac{12}{100}$	.13%	.07%
	PbO 60 grams											
	Niter 1 gram	2	28	—	—	.06820	.00011	.00015	.06846	$68\frac{46}{100}$	.16%	.22%
	Cover of salt											

From the foregoing tables it is very evident that the ore, setting aside the loss through volatilization, assays between 68 and 69 ounces per ton, and any results below this are due to the ore weighed out not being a correct or even sample of the whole. Of the eight scorification assays three are practically correct, and are within the limits of error of assay with no correction made for the gold found in the slag and cupel. The remaining five are all too low, even with the corrections made, and there seems no way for accounting for these low results other than that the portion of ore taken was an incorrect sample of the whole.

The crucible results are much more even, and the percentage of loss sustained both in the slag and in cupellation lower than in the scorification method. As the amount of ore taken is five times larger in seven cases, and ten times larger in two cases than in the scorification method, this may account for the more uniform results and the smaller percentage of loss sustained.

As for the charges used, no comparison is drawn. Our only regret is that the sample of ore was so small that we were unable to carry out further experiments which the above results suggest. No doubt if the ore had been crushed to pass through a 160 or 180-mesh sieve, more uniform results would have been obtained in the scorification method. It was only a short time ago when a 60-mesh sieve was considered sufficiently fine to pass any ore through previous to assaying. This was then set aside for an 80-mesh, and now a 100-mesh is generally used in most assay offices. I believe it only a question of time when every sample will have to pass a 140-mesh. What assayers need is a machine easily cleaned, which will grind ores through such a sieve quickly, and at the same time not contaminate the sample with the iron or material of which the machine is made. The foregoing experiments also bring up the questions of how close assay results should check, and what the percentage of loss is in assay work.

As to the first question, some ores will check easily, even if the ore is ground no finer than through a 60-mesh sieve, but these are the exceptions. With other ores, even when ground so fine that they will pass through bolting cloth finer than 200 meshes to the inch, it seems impossible to obtain anything like uniform results.

As to the percentage of loss sustained in work, whether by the scorification or the crucible method, many experiments carried out upon the foregoing lines, both upon silver and gold ores, indicate to me that nothing definite can be laid down in regard to it. Every ore, every slag, every scorification, and every cupel, let alone the temperature at which the assay is carried on, has some effect upon the loss, and these make too many unknown quantities to arrive at any definite conclusion.

NOTES ON AN UNUSUAL ORIENTATION OF PHENOCRYSTS IN A DIKE.

By MYRON L. FULLER.

Received April 21, 1899.

PORPHYRITIC crystals, or phenocrysts, as they have been named by Iddings, are the more or less perfect crystals of igneous rocks occurring in a matrix, or ground mass, of smaller and more irregular individuals, or in a glass. The usual view is that they represent the crystallization of an earlier and deeper (intratelluric) stage of the magma before its final intrusion or ejection, as the case may be. In those instances where their major axes have an orientation parallel to the walls (in intrusions) or to the surface of the flow (in extrusive masses) the evidence is clear that the arrangement is due to the flowage of the magma, and indicates conclusively a prior existence of the phenocrysts. The necessity of considering them in all cases as representing an intratelluric stage has, however, been doubted by several petrographers of note,[1] and recently Pirsson[2] has strongly urged *development in place* as the probable explanation for practically all phenocrysts of intrusive rocks.

There are four general ways in which phenocrysts may be arranged in a dike. In the first, the individuals may be distributed, either regularly or irregularly, throughout the mass and possess no definite orientation of their axes; in the second, the larger axes have an orientation parallel to the walls of the dike; in the third, the longer axes lie in a horizontal plane, while in the fourth there is a parallel arrangement other than horizontal, and having no relation to the walls.

It is to the third or fourth group that the occurrence to be described belongs. The dike in question was noted on the shore of Rand's Pond in the town of Goshen, Sullivan County, New Hampshire, and is exposed for a distance of some 175 feet. It varies in width from 1 to 3 feet. The wall rock is a rather coarse, dark colored, micaceous gneiss

[1] Zirkel, Lehrbuch der Petrographie, Vol. I, p. 731, et seq. 1893. Cross, 14th Ann. Rept. U. S. Geol. Surv., p. 231.

[2] Am. J. Sci. IV, Vol. 7, 271–280.

with a well developed lamination. On the map[1] it is given as the "fine grained" Bethlehem gneiss, but to the eye is indistinguishable from much of the Winnipiseogee gneiss, which, however, is not indicated as appearing for nearly a mile to the westward.

The dike rock is a porphyritic granite similar in its general character to that of a large area of porphyritic granite (designated as the Main Area[2]), the western boundary of which lies only about two miles to the eastward. The interest in the dike arises from the unusual orientation of the orthoclase phenocrysts. These are from 1 to 2 inches in length, and possess a common orientation which, instead of being parallel to the walls, agrees exactly with the lamination of the

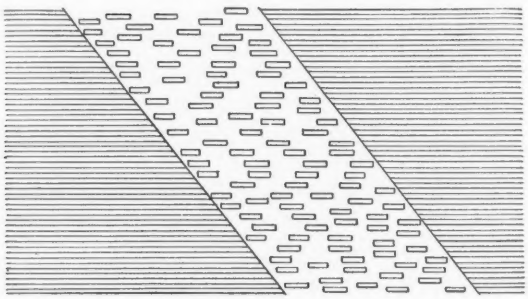

FIG. 1.—SECTION PARALLEL WITH STRIKE, SHOWING RELATION OF PHENOCRYSTS TO LAMINATION OF THE GNEISS. RAND'S POND, GOSHEN, N. H.

neighboring gneiss, which here dips to the eastward at an angle of some 35°. This relation is clearly brought out in the figure.

In seeking a cause of the arrangement it is necessary to make certain assumptions as to the conditions obtaining at the time of solidification. We can either consider that the lamination of the gneiss and the orientation of the phenocrysts were both horizontal at the time of solidification of the dike, or we may regard the present attitudes as original.

Leaving out of account the horizontal lamination which the gneiss would have possessed under the former of these suppositions, and which would point towards a sedimentary origin, there remains the

[1] Atlas accompanying the Report on the Geology of New Hampshire. C. H. Hitchcock, 1878.

[2] Daly, Jour. Geol., 5, 702.

horizontal arrangement of the phenocrysts to be accounted for. This arrangement would exclude the agencies of pressure and flowage as determining causes, and the action of gravity seems to be the only agent available.

Tabular particles, especially if of considerable size, tend, when settling in a solution of nearly equal specific gravity, to sink with their broader planes in a roughly horizontal position. Thus phenocrysts, if heavier than the inclosing magma, might be conceived as arranging themselves in parallel positions if the dike was vertical. In the case in question the dike would have cut the horizontal gneiss at a large angle, and if any settling of the phenocrysts had occurred, there would inevitably have been some tendency along the foot wall (because of the arrest of the phenocrysts) to an arrangement parallel to its plane.

It is, however, extremely doubtful if phenocrysts of orthoclase would settle at all in a granitic magma of the type occurring in the dike. It is true that a certain increase in density takes place when minerals crystallize from a magma, but Mallet's observations on the solidification of plate glass, taken as a representative of acid rocks, show that the increase is very slight (about 1.6 per cent.). This would be offset, in all probability, by the greater basicity of the remaining magma. The fact that while the specific gravity of the orthoclase is not over 2.59, that of the surrounding granite is approximately 2.73, gives weight to this view.[1]

The viscosity of the magma would also tend to so neutralize the effect of slight differences of density that a sinking by gravitation, if it took place at all, would be comparatively unimportant in character, especially while the magma retained its upward motion.

The absence of a feasible explanation of the arrangements of the phenocrysts under the conditions assumed is a strong argument against the existence of such conditions. We are led, therefore, to the consideration of the second supposition, *i. e.*, that the attitude of the lamination of the gneiss and the orientation of the phenocrysts have remained unchanged since the consolidation of the dike. Flowage is again ruled out as a possible cause of the orientation. Gravitation is likewise eliminated because of the inclination of the laminæ of the gneiss to which the phenocrysts are parallel.

[1] The specific gravity determinations were made upon the porphyritic granite from the Fitchburg, Mass., district, no specimens from the dike itself being available. The two are, however, identical in character.

Pressure seems to be the only agency capable of producing the features observed. If, while the magma was still plastic, it was subjected to pressure, the mobility of its particles would be sufficient to readily admit of an orientation of the phenocrysts in planes perpendicular to the direction of the pressure, in a manner analogous to that of mica scales in the experiments of Sorby on slaty cleavage. Likewise, if deeply buried, the heat and pressure acting during a period of compression might easily be sufficient to cause the rocks to behave as if plastic, and the same orientation would result. The action of

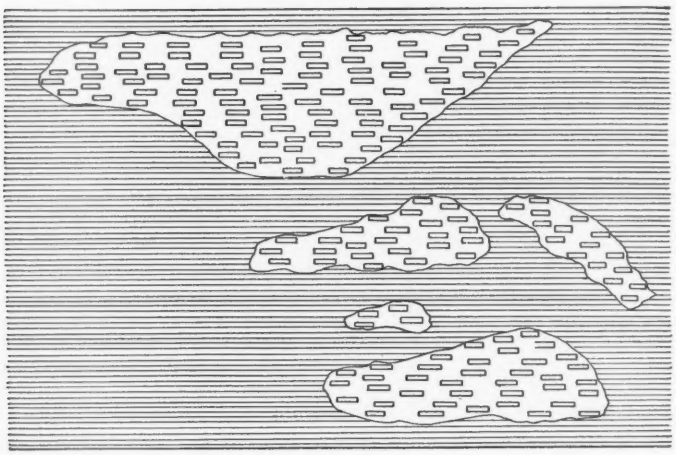

FIG. 2. — PLAN, SHOWING RELATION OF THE PHENOCRYSTS OF INCLUSIONS TO THE LAMINATION OF THE INCLOSING GNEISSIC GRANITE. SUNAPEE, N. H.

pressure on the plastic rock is probably the true explanation of the unusual orientation described.

What is probably an analogous case is found in the fragments of banded porphyritic granite included in the so-called Winnipiseogee gneiss on a hill in the southern part of the town of Sunapee. Here, whatever the relation of the included fragments to the lamination of the gneiss, there is a close agreement, in all cases noted, between the orientation of the phenocrysts and the lamination.

Figure 2 shows the arrangement of such a group of inclusions.

That such a uniform parallelism of orientation should be due to an accidental arrangement is highly improbable, and connection with the

parent rock is impossible. The only feasible view seems to be that the orientation here, as in the case of the dike, was due to the action of pressure upon the more or less plastic inclusions. This view finds support from the nature of some of the contacts. The inclusions of the granite gradually become less massive as the gneiss is approached, and show a fraying out, until finally the only indication of the former extension of the granite is the occurrence of badly corroded phenocrysts in the adjoining gneiss. A degree of heat capable of producing such results is amply sufficient to account for the assumed plasticity of the inclusions.

The relation of the porphyritic granite to the gneiss here noted is just the reverse of that assumed by Daly[1] from apparently unimpeachable evidence. This apparent inconsistency may be due to the fact that the area mapped as Winnipiseogee gneiss may, in reality, include several rocks of similar appearance but of diverse origin, some of which are older and some younger than the porphyritic granite. The diverse natures of the rocks of the Winnipiseogee series was noted by Daly.[2]

The correspondence between the lamination of the so-called gneisses and the arrangement of the phenocrysts, which is so marked in both instances described, might appear to indicate a similar origin for both. This, however, is probably not the case. Daly has shown[3] that the lamination of the porphyritic granite is, in all probability, a flow structure. The so-called Winnipiseogee gneiss, at least in the locality described in the town of Sunapee, appears from its field relations to be likewise an igneous intrusion, and it is not unlikely that the lamination is a flow structure. The axes of disturbance in this region have a general north-south direction, or, in other words, are parallel to the main intrusive masses. The pressure, which would normally be at right angles to the flow structure, would therefore cooperate with it. In the small dikes, on the other hand, which cut diagonally across the lamination of the inclosing rocks, the direction of pressure would be inclined to the lines of flow, and would act more or less in opposition to it. At Rand's Pond pressure was clearly the predominating factor in determining the orientation.

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[1] Jour. Geol., 5, 708–713, 720–722.
[2] Jour. Geol., 5, 721.
[3] Jour. Geol., 5, 780–789.

ON A METHOD OF MEASURING THE FREQUENCY OF ALTERNATING CURRENTS.

By HARRISON W. SMITH.

Received April 24, 1899.

The following is a brief description of a method recently employed at the Institute for measuring variations in the frequency of currents of about 120 alternations per second. With the exception of Figure 2 the diagrams are not drawn to scale, while Figure 1 is devoted largely to the arrangement of connections used in the electrical driving of the tuning fork.

A weighted fork (Figure 1) is mounted horizontally and is provided with a metallic contact-maker *D*, consisting of a sharp-pointed stile

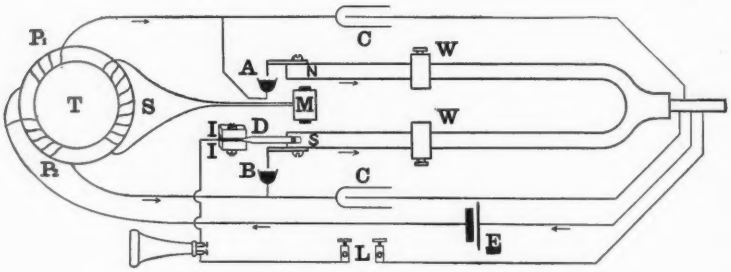

Fig. 1.

(attached to the prong *S*) which vibrates over a smooth surface formed by two blocks of ivory *I I*, separated by a sheet of platinum about 0.02 inch thick. The ivory blocks are firmly clamped together and the surface is then highly polished, so that the stile while vibrating and pressing lightly against it shall encounter as little friction as possible. This part of the contact-maker is so mounted as to be capable of vertical adjustment in order that the stile may make contact with the platinum at the middle of the stroke of the prong. The contact-maker is then connected in series through the fork with a telephone (Figure 1) and attached at *L* to the source of alternating current, the

frequency of which is to be measured. When, now, the fork is set in vibration, the stile makes contact at the middle of each stroke of the prong, and if the periodicity of the alternating current is the same as that of the fork, the contacts will occur at the same point on each successive current wave: there will then be a steady sound in the telephone or no sound, depending on the difference of phase between the current and the fork. If, however, the periodicity of the current and fork differ slightly, there will be fluctuations of sound causing marked "beats;" the frequency of the beats depending on the amount by which the periodicity of the current and fork differ. The weights *W W* are then adjusted by repeated trials until there are no beats, and as the fork has been previously rated, we know directly the periodicity of the current.

Figure 2 indicates the manner in which the beats occur. *AB* and *AC* on the same scale represent, respectively, ten complete sinusoidal

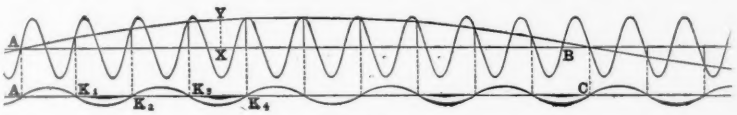

FIG. 2.

alternations of current and ten single vibrations of the fork; ten vibrations of the fork occupying the same time as ten and one-half alternations of the current. If, then, K_1, K_2, etc., are the points at which the fork makes contact, it follows that ordinates to the current curve, at corresponding points, will indicate the strength of the current in the telephone, and consequently the intensity of the sound. The curve of which *XY* is an ordinate is, then, the "sound" curve, and there is one beat for every half period by which the current precedes or lags behind the fork. An inspection of the curve shows that if the frequency of the current were one-half as great, or one and one-half times as great as shown in Figure 2 (the periodicity of the fork remaining unchanged), there would again be no beats. Thus, as is in general the case, it is necessary to know approximately the periodicity which is to be measured accurately. It follows, further, that a given fork will measure periodicities other than those at which it is rated. If the fork, for example, has a range from 110 to 130 single vibrations per second, it will, as we have seen, measure periodicities ranging from 110 to 130 complete alternations per second. If, however, the

periodicity of the current were between 55 and 65, or between 165 and 195, the fork could still be adjusted for no beats, so that the same fork will serve equally well for measuring periodicities ranging within those limits.

As shown above, under the conditions where one single vibration of the fork is nearly equal in time to one alternation of the current, one beat occurs for every half period by which the current differs from the fork. Therefore, if the source of current is a dynamo giving 120 alternations per second, and the fork is adjusted for no beats, and the speed of the dynamo then changes so that there is one beat every five seconds, we know that the speed of the dynamo has changed by one alternation in ten seconds or by one part in twelve hundred. This suggests a method of measuring fluctuations in speed of any machine to which a small alternating generator can be attached: if applied to an engine, it would show the controlling action of the governor. For this purpose it would be necessary to so adjust the fork that its period would always be greater or less than that of the current; for if, when the periodicity of the current were fluctuating, the fork and current came sometimes into unison, there would be no convenient means of determining from the beats when they occurred, whether the periodicity of the current had increased or decreased. For continued observations it might be desirable to substitute for the telephone some simple recording device.

The method of driving the fork electrically is a modification of the method of W. G. Gregory (Phil. Mag., Dec., 1889, p. 490). The fork is magnetized with its prongs forming the north and south poles, between which is mounted an electro-magnet M (Figure 1). This magnet is connected to the secondary coil of a small ring transformer T, which has two primary coils P_1 and P_2, wound in opposite directions. A and B are mercury contact-makers connecting a storage cell E to the coils P_1 and P_2 respectively, and so adjusted that, at about the middle of the stroke of the prongs, the circuit is simultaneously closed in one and opened in the other. Thus, when the prongs are approaching each other, the current is flowing in P_2 until the prongs reach the middle of their stroke; at that point the circuit in P_2 is broken and that in P_1 is closed. The current in P_1 then reverses the magnetism of the core, inducing a momentary current in S which causes M to exert an attraction on the prongs N and S. When, however, the prongs are receding from each other the circuit is opened in

P_1 and closed in P_2, and the induced current in S causes M to exert a repulsion on N and S. The fork receives an impulse then at the middle of each stroke. Gregory uses but one primary coil on the transformer, and the fork is driven by the induced currents due to making and breaking the primary current. As, however, the change in magnetic flux in a soft-iron, closed-circuit transformer is more than ten times as great when the magnetizing force is reversed, as when it is simply removed, the modified method admits of the use of very much less current in the primary circuit. The core of the transformer was a ring consisting of 125 turns of No. 23 iron wire with a mean diameter of 8 c. m. The secondary coil consisted of 250 turns of No. 20 copper wire wound outside the two primary coils, each of which had 150 turns of No. 24 copper wire. Less than $\frac{1}{3}$ ampere was sufficient to drive the fork. Moreover, the use of two coils, together with the smaller current, reduced the sparking very materially, and, with a condenser C of 0.3 microfarad across the contacts, the sparking was scarcely perceptible.

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